Climate Change and Extreme Weather Adaptation Options

for Transportation Assets in the Bay Area Pilot Project

Technical Report • December 2014

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TABLE OF CONTENTS

LIST OF FIGURES

Figure **Page**

LIST OF TABLES

Tables **Page**

ACRONYMS AND ABBREVIATIONS

AADT	Annual Average Daily Traffic
ABAG	Association of Bay Area Governments
AC Transit	Alameda-Contra Costa Transit District
ACES	Automated Coastal Engineering System
ACFCWCD	Alameda County Flood Control and Water Conservation District
ART	Adapting to Rising Tides
BAAQMD	Bay Area Air Quality Management District
BAARI	Bay Area Aquatic Resource Inventory
BART	Bay Area Rapid Transit
Bay	San Francisco Bay
BCDC	San Francisco Bay Conservation and Development Commission
BFS	BART Facility Standard
CA	California
Caltrans	California Department of Transportation, District 4
CC	MTC Communities of Concern
CCAT	California Climate Action Team
CCJPA	Capitol Corridor Joint Powers Authority
CCMP	California Coastal Mapping Program
CDFG	California Department of Fish and Game
CEC	California Energy Commission
CEM	Coastal Engineering Manual
CEO	Chief Executive Officer
CEQA	California Environmental Quality Act
CESA	California Endangered Species Act
CO	Carbon Monoxide
CO2	Carbon Dioxide
CSMP	California Seafloor Mapping Project
CT	Consultant Team
CWA	Clean Water Act
CZMA	Coastal Zone Management Act
DDF	Depth Duration Frequency
DEM	Digital Elevation Model
EBRPD	East Bay Regional Park District
EO	Executive Order
ER	Emergency Relief
ERM	Enterprise Risk Management
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GEV	Generalized Extreme Value
GHG	Greenhouse Gases
GIS	Geographic Information System

GO	General Obligation
GPWG	Gateway Park Working Group
HARD	Hayward Area Recreation and Park District
HDM	Highway Design Manual
HEC-RAS	Hydrologic Engineering Center – River Analysis System
I-	Interstate
IPCC	Intergovernmental Panel on Climate Change
LiDAR	Light Detection and Ranging
MHHW	Mean High Higher Water
MLK Regional Shoreline	Martin Luther King Regional Shoreline
MLLW	Mean Lower Low Water
MPO	Metropolitan Planning Organization
MTC	Metropolitan Transportation Commission
NA	Not Applicable
NAD	North American Datum
NAVD	North American Vertical Datum
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Policy Act
NOAA CSC	National Oceanic and Atmospheric Administration Coastal Services Center
NOx	Oxides of Nitrogen
NRC	National Research Council
O&M	Operations & Maintenance
OAC	Oakland Airport Connector
OCOF	Our Coast Our Future
PDA	Priority Development Area
PDT	Project Development Team
PID	Project Initiation Documents
PM	Particulate Matter
PMT	Project Management Team (MTC, BCDC, Caltrans, BART)
ROG	Reactive Organic Gases
RTEMP	Regional Transportation Emergency Management Plan
RTP	Regional Transportation Plan
RWQB	Regional Water Quality Board
SCC	California State Coastal Conservancy
SCS	Sustainable Communities Strategy
SDSI	Storm Drain System Inventory
SFEI	San Francisco Estuary Institute
SHS	State Highway System
SLC	State Lands Commission
SLR	Sea level rise
SPM	Shoreline Protection Manual
SR	State Route
STAG	Statewide Transportation Asset Geodatabase
SWEL	Stillwater Elevation
TAZ	Transport Analysis Zone

TRID	Transport Research International Documentation
TT	Technical Team
USACE	U.S. Army Corps of Engineers
USDOT	United States Department of Transportation
USGS	United States Geographical Survey
VHD	Vehicle Hours of Delay
VHT	Vehicle Hours Traveled
VMT	Vehicle Miles Traveled
VPD	Vehicles Per Day
WAFO	Wave Analysis for Fatigue and Oceanography
WWTP	Waste Water Treatment Plant

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Executive Summary

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EXECUTIVE SUMMARY

INTRODUCTION (CHAPTER 1)

The nine-county San Francisco 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 to the rest of the region, the state, the nation, and the world. According to current projections (National Research Council, 2012), climate change could cause the Bay to rise by 12 to 24 inches by midcentury and by 36 to 66 inches by the end of the century. This means that today's floods will be the future's high tides and areas that currently flood every 10–20 years will flood much more frequently. Neighborhoods, businesses, and entire industries that currently exist on the shoreline will be subject to this flooding and the many other direct impacts that will result from it. These shoreline areas in the bay are home to more than 250,000 residents who will be directly affected and many others, including workers, who will be indirectly affected by reduced access to important services, such as transit and commercial centers, health-care facilities, and schools[1]. Given the complexity of the shoreline and its management, it is essential to start to develop adaptation strategies now, to protect the prosperity of the Bay Area and its inhabitants in the future.

The Metropolitan Transportation Commission (MTC), the San Francisco Bay Conservation and Development Commission (BCDC), the California Department of Transportation, District 4 (Caltrans) and San Francisco Bay Area Rapid Transit District (BART) have partnered on a collaborative sub- regional pilot project to assess adaptation options for a subset of key transportation assets vulnerable to sea level rise (SLR) in Alameda County. This study builds on the *Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project*[2] which was completed in 2011 and identified representative critical transportation assets vulnerable to sea level rise (SLR). Both projects were funded by the Federal Highway Administration (FHWA). The first study developed detailed risk profiles for approximately 30 transportation assets including road, rail and transit. Having identified the risks, and in order to move from assessment to action, three focus areas within Alameda County containing 'core' transportation assets and 'adjacent' community assets were selected for further study to ensure a thorough understanding of their vulnerabilities. Once that enhanced vulnerability had been assessed, a set of detailed, representative adaptation strategies have been developed as potential solutions to protect key bridge, highway, transit and community assets from future inundation.

PROJECT GOALS

The detailed project goals were to develop:

- A refined understanding of vulnerability and risk for the core transportation assets in three focus areas within the Alameda County sub-region
- A refined understanding of SLR and storm event exposure in the three focus areas by analyzing the extent, depth, and pathways of inundation caused by overtopping of specific shoreline segments
- High-level climate adaptation options on three scales: (1) the core transportation assets alone, (2) the core transportation assets with key adjacent assets, and (3) each focus area as a whole

1 Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November, 2011 http://www.mtc.ca.gov/planning/climate/RisingTides-TechnicalReport.pdf

2 Ibid.

- Five refined representative adaptation options with specific and detailed actions including identification of timing, responsible parties, and methods for implementation
- A suite of criteria used first to select representative adaptation strategies from the long list and then second to evaluate the high-level climate adaptation strategies selected for further development.

THREE FOCUS AREAS

Three focus areas were selected for study within Alameda County based on their vulnerability and risk as identified in the previous study:

- The San Francisco-Oakland Bay Bridge Peninsula – ‘Bay Bridge Touchdown Focus Area’
- The Oakland Coliseum Area – ‘Coliseum Focus Area’
- The State Route 92 Corridor – ‘Hayward Focus Area’

The three focus areas include a confluence of major regional transportation assets and are interwoven with other important regional and community assets. The transportation infrastructure in the three focus areas includes assets critical to the region’s mobility and economy, such as multimodal hubs, I-80, I-880, State Route (SR) 92, two critical bridges (the San Francisco-Oakland Bay Bridge (I-80) and the San Mateo-Hayward Bridge (SR 92)), arterial and collector streets, BART (stations, track and infrastructure), and passenger and freight rail lines. These transportation assets are surrounded by a diversity of land uses and community assets, including a wastewater treatment plant (WWTP), regional parks and neighborhood businesses among others, that can experience co-benefits from adaptation strategies. One of the focus areas (the Coliseum Focus Area) also includes a Priority Development Area (PDA), where the anticipated housing and job growth is expected to occur as identified in Plan Bay Area, the San Francisco Bay Area Sustainable Communities Strategy (SCS) / Regional Transportation Plan (RTP) required by State and federal law. The SCS describes land use development patterns and transportation investments intended to reduce greenhouse gas emissions by better aligning development with the transportation network, including existing and planned high quality transit. Maps identifying the three focus areas and the selected assets are found in Chapter 1.

TRANSPORTATION ASSET INVENTORY AND DATA COLLECTION (CHAPTER 2)

A set of core transportation and adjacent community assets was identified at the start of the project based on information developed in the 2011 pilot. A step-by-step process was then used to collect and organize data on those assets to support the subsequent detailed vulnerability assessment and adaptation strategy development. The primary steps in this process included:

- Preliminary identification of data needs and existing resources available to meet those needs;
- Identification of asset components for review (where the 'core' asset was large and included multiple components with different characteristics, such as I880 from Coliseum Way to 98th Avenue for which the Damon Slough Bridge, Elmhurst Creek Bridge and Tributary Drainage Areas were selected as components for study)
- Development and administration of an online survey to collect information about core and adjacent assets and asset components from agency staff
- Creation of a robust transportation asset inventory

This data was collected for all the assets shown in Table I. Maps identifying the three focus areas and the selected assets are provided in Chapter 1.

Data was sought on the vulnerabilities of the assets (and their components) to future climate impacts to help answer a suite of assessment questions based on questions developed by the Adapting to Rising Tides[3] (ART) project which were refined for the assets under consideration in this project. The consultant team developed 102 asset-related survey questions (see Appendix A). The questions were organized in the following categories:

- **Governance Challenges (management/control):** Questions on management and regulation were included to determine whether an asset or asset category is vulnerable due to challenges with management, regulation, or availability of financing resources or flexibility of funding or permitting
- **Information Challenges:** Questions on information metrics were included to determine whether there are ways in which an asset or asset category is vulnerable due to deficient, incomplete, or poorly coordinated information
- **Physical Characteristics:** Questions on physical characteristics were included to determine whether an asset or asset category may be vulnerable due to how an asset is designed or built
- **Functional Characteristics:** Questions on functional characteristics were included to determine whether an asset or asset category is vulnerable due to dependencies and interrelationships with other assets and asset categories.
- **Consequences of Climate Change:** Questions were included on the potential consequences of climate change for an asset or asset component on society and equity, the environment and the economy to inform potential adaptation strategies

Significant effort was taken to gather this information on the core and adjacent assets. The data received was geocoded (assigned attributes within a GIS platform) so that it can be readily used by the agencies for analysis in the future.

[3] The San Francisco Bay Conservation and Development Commission (BCDC) partnered with the National Oceanic and Atmospheric Administration Coastal Services Center to work with San Francisco Bay Area shoreline communities on planning for sea level rise (SLR) and other climate change–related impacts. The overall goal of the project, called Adapting to Rising Tides (ART), is to increase the preparedness and resilience of Bay Area communities to SLR and other climate change–related impacts while protecting ecosystem and community services.

Table I: Core and Adjacent assets

BAY BRIDGE TOUCHDOWN FOCUS AREA	
Core Assets	**Asset components**
I-80/I-580 Powell Street to the Toll Plaza (Core)	Bay Bridge Toll Plaza Temescal Creek Bridge Tributary Drainage Areas[4]
I-880 from 7th Street to the Toll Plaza (Core)	Tributary Drainage Areas[5]
East end of Transbay Tube including Track Portal (Core)	n/a
Adjacent Assets	
EBMUD Main Wastewater Treatment Plant (WWTP)	n/a
Burma Rd. Port Operations	n/a
Burma Rd. Electrical Substation	n/a
Eastshore State Park / Emeryville Crescent	n/a
COLISEUM FOCUS AREA	
Core Assets	**Asset Components**
BART Oakland Airport Connector	Rail stations (Airport and Coliseum) Wheelhouse or Doolittle Maintenance Facility
I-880 from Coliseum Way to 98th Ave.	Damon Slough Bridge Elmhurst Creek Bridge Tributary Drainage Areas[6]
BART Station	Traction power substation Train control room A30 Tunnel
Amtrak Station and Union Pacific Rail Mainline	n/a
Adjacent Assets	
Martin Luther King (MLK) Regional Shoreline, East Creek to Arrowhead Marsh	Arrowhead Marsh
Coliseum Arena Complex	n/a
San Leandro Street	n/a
HAYWARD FOCUS AREA	
Core Assets	**Asset Component**
SR 92	San Mateo - Hayward Bridge Toll Plaza (1st and 2nd approach) Tributary Drainage Area[7]
Bay Trail	Johnson's Landing to Breakwater Avenue Pedestrian bridge over SR 92 SR 92 to Arden Road parking lot
Adjacent Assets	
Eden Landing Ecological Reserve	n/a
Oliver Salt Ponds	n/a
Industrial land uses west of Industrial Blvd	n/a
Hayward Shoreline Interpretive Center	n/a

4 There are five separate tributary drainage areas along I-80/I-580 between the Toll Plaza and Powell Street with storm drain systems to drain water from the freeway.

5 There are five separate tributary drainage areas along I-880 between 7th Street and the Toll Plaza with storm drain systems to drain water from the freeway.

6 There are three separate tributary drainage areas along I-880 between the 66th Avenue and 98th Avenue with Caltrans operated storm drain systems to drain water from the freeway

7 There is one tributary drainage area along SR-92 that starts just west of the toll plaza and ends east of the Hayward Shoreline Interpretive Center with storm drain systems to drain water from the freeway.

EXPOSURE AND VULNERABILITY REFINEMENT RESULTS (CHAPTER 3)

The first MTC pilot study, *Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, 2011* [8] identified the exposure of the three focus areas to two SLR scenarios (16-inch and 55-inch) as well as a 100-year storm surge and a wind-wave scenario. However, as there are large differences between the inundations for these two SLR scenarios, a more refined analysis was undertaken of potential exposure to future sea level rise for this study. The National Research Council's (NRC, 2012) most recent sea level rise projections considered a range of potential sea level rise projections, considering both the rates that were most likely to occur, as well as upper and lower uncertainty bounds that were possible given the current uncertainties in some of the factors that contribute to global and local sea level rise projections. NRC (2012) suggests that it is likely that the Bay will rise by at least 12 inches by midcentury and 36 inches by end of century; however, it is possible that sea levels could rise by as much as 24 inches by mid-century and 66 inches by end-of-century.

In accordance with this data, the following scenarios (see Table II) were developed by adding different levels of SLR onto the elevation of the existing daily high tide level (represented by the Mean Higher High Water (MHHW) tide): MHHW +12-inch, 24-inch, 36-inch, and 48-inch. In addition to these scenarios, MHHW +72-inch and 96-inch were evaluated, but these water levels are outside the range of current scientific predictions for SLR and, therefore, do not correspond with permanent inundation scenarios that are likely to occur before 2100 (NRC, 2012). These scenarios are included to evaluate important extreme flooding scenarios that could happen during storm surge events with lesser amounts of SLR. In general, though, the scenarios can occur due to SLR, storm surge, or a combination of the two.

Table II: Sea Level Rise Inundation Scenarios

Mapping Scenario	Reference Water Level	Applicable Range for Mapping Scenario (Reference +/- 3 inches)
Scenario 1	MHHW + 12-inch	MHHW + 9 – 15 inch
Scenario 2	MHHW + 24-inch	MHHW + 21 – 27 inch
Scenario 3	MHHW + 36-inch	MHHW + 33 – 39 inch
Scenario 4	MHHW + 48-inch	MHHW + 45 – 51 inch
Scenario 5	MHHW + 72-inch	MHHW + 69 – 75 inch
Scenario 6	MHHW + 96-inch	MHHW + 93 – 99 inch

* Colors in the table relate to the water levels in Table 3-2

It is important to understand that the reference water levels listed for each scenario can occur due to a variety of hydrodynamic conditions by combining different amounts of SLR with either a daily[9] or extreme high tide. A +/- 3 inch tolerance was added to each reference water level to increase the applicable range of the mapped scenarios. For example, Scenario 3 (MHHW + 36-inch) is assumed to be representative of all extreme tide/SLR combinations that produce a water level in the range of MHHW + 33 inches to MHHW + 39 inches. An extreme tide is defined here as a relatively high astronomical tide that coincides with a storm surge event to produce significantly elevated water levels. By combining different amounts of SLR and extreme tide levels, a matrix of water level scenarios was developed to identify the various combinations represented by each inundation map for the focus areas.

[8] http://www.mtc.ca.gov/planning/climate/RisingTides-TechnicalReport.pdf

[9] Mean Higher High Water (MHHW) is used as a surrogate for the average daily high tide. MHHW is the average of the higher high water level of each tidal day observed over the National Tidal Datum Epoch. It should be noted that the actual higher high tide that occurs on any given day will be higher or lower than MHHW. MHHW is approximately 7.0 ft. NAVD88 within this focus area.

As an example, the matrix of SLR and tide scenarios for the Hayward Focus Area is presented in Table III. The values in Table III are in shown in inches above the existing conditions MHHW tidal level. The colors match the colors shown in Table II, and indicate the different combinations of SLR and extreme tide scenarios. The first row of the Table III shows values for existing conditions. For example, , the MHHW + 36-inch scenario (Scenario 3), would also represent a 1-yr extreme tide event with 24 inches of SLR, a 2-yr extreme tide event with 18 inches of SLR, a 5-yr extreme tide event with 12 inches of SLR, etc. Equivalent water levels for the MHHW + 12-inch, MHHW + 24-inch, MHHW + 36-inch, MHHW + 48-inch, MHHW + 72-inch, and MHHW + 96-inch scenarios can be determined similarly by tracking the color coding through Table III. Terms such as "X-inch scenario" and "MHHW + X-inch" are used throughout this section to refer to specific inundation scenarios (e.g., "48-inch scenario" or "MHHW + 48-inch" instead of "48 inches of SLR") since the scenario can be associated with multiple combinations of SLR and extreme tide events. The matrices of SLR and tide scenarios can also be used to plan for a particular level of risk. For example, to examine infrastructure exposure to a 100-yr extreme tide event with an estimated 6 inches of SLR, the MHHW + 48-inch scenario could be examined. Using this approach, it is possible to assess flood risk to assets at various time scales and frequency of flooding.

Table III: Matrix of Water Levels Associated with Sea Level Rise and Extreme Tide Scenarios for the Hayward Focus Area

	Daily Tide	Extreme Tide (Storm Surge)						
Sea Level Rise Scenario	Water Level above MHHW	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Existing Conditions	0	15	20	24	27	32	36	41
MHHW + 6-inch	6	21	26	30	33	38	42	47
MHHW + 12-inch	12	27	32	36	39	44	48	53
MHHW + 18-inch	18	33	38	42	45	50	54	59
MHHW + 24-inch	24	39	44	48	51	56	60	65
MHHW + 30-inch	30	45	50	54	57	62	66	71
MHHW + 36-inch	36	51	56	60	63	68	72	77
MHHW + 42-inch	42	57	62	66	69	74	78	83
MHHW + 48-inch	48	63	68	72	75	80	84	89
MHHW + 54-inch	54	69	74	78	81	86	90	95
MHHW + 60-inch	60	75	80	84	87	92	96	101

Note: All values in inches above existing conditions MHHW at the Hayward Focus Area. The extreme tide levels above MHHW were derived from the FEMA MIKE 21 model output. Color coding indicates which combinations of sea level rise and extreme tides are represented by the mapping scenarios shown in Table 3-1. Cells with no color coding do not directly correspond to any of the mapping scenarios shown in Table 3-1.

Examples of the inundation maps can be found in the Technical Memos in Appendix B. Based on the inundation maps that were produced as a result of the flooding exposure analysis, the most vulnerable assets were identified within each of the focus areas.

COLISEUM FOCUS AREA – ADDITIONAL RIVERINE FLOODING ANALYSIS

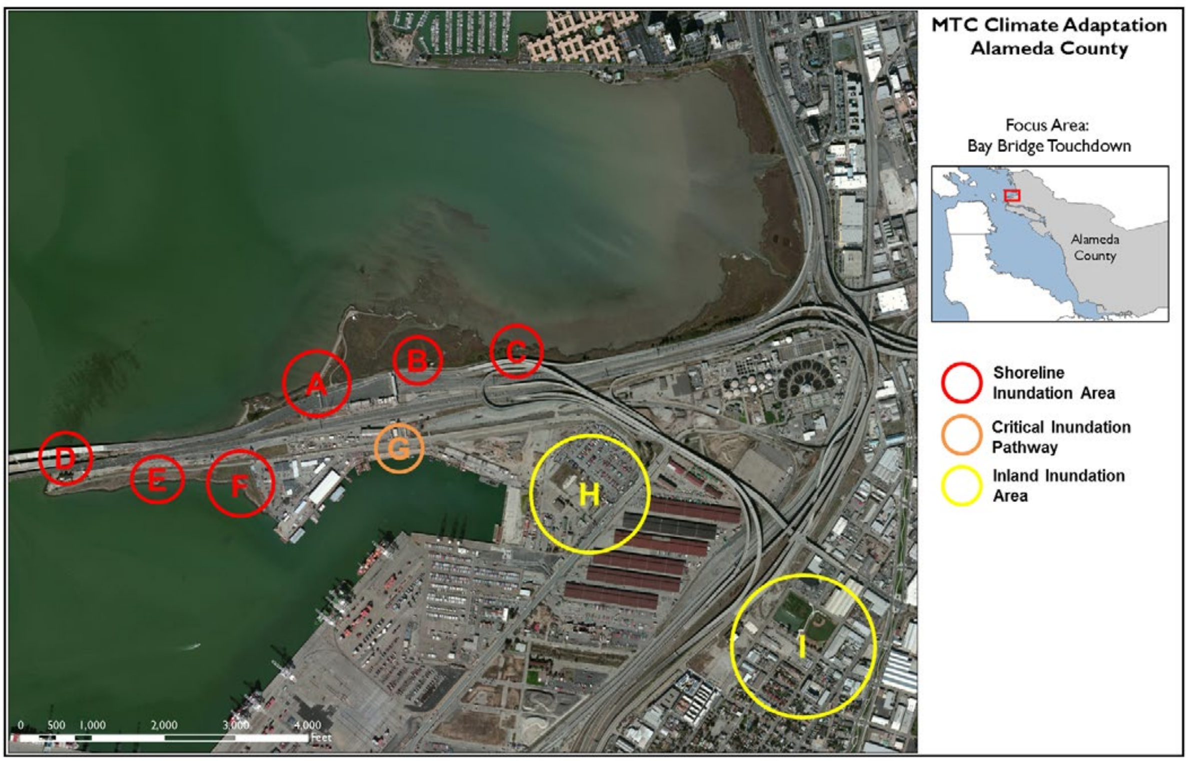
For the Coliseum focus area, an additional riverine flooding analysis was undertaken, as this region is expected to experience a combination of SLR and riverine flooding in the future. Based on the inundation maps that were produced as a result of the SLR and riverine flooding exposure analysis, the most vulnerable assets were identified within the focus area. Full details of the analysis undertaken can be found in Appendix B.

RESULTS OF REFINED EXPOSURE ANALYSIS

BAY BRIDGE TOUCHDOWN FOCUS AREA

Nine key areas of vulnerability within the Bay Bridge Touchdown Focus Area were identified based on the results of the inundation mapping. Timing of inundation and proximity to important assets were the fundamental criteria used to select these areas, which are identified in Figure I and labeled letters “A” through “I”. These areas are grouped into three categories -- *shoreline inundation areas*, *critical inundation pathways*, and *inland inundation areas*. In Figure I, shoreline inundation areas (A-F) are labeled in red, critical inundation pathways (G) in orange, and inland inundation areas (H-I) in yellow. They are discussed in detail in Section 3-3.

Figure I: Bay Bridge Touchdown Focus Area Site Location Map and Inundation Areas



Note: Circles are used to indicate approximate locations and extents of inundation. Circle sizes do not correspond to intensity, timing, or risk of inundation.

Shoreline inundation areas are immediately adjacent to the shoreline and are both the most vulnerable to flooding and the most likely to experience permanent inundation as a result of sea level rise. These areas are where the shoreline will first be overtopped and from which floodwaters will propagate to areas inland. Six shoreline inundation areas were identified for the Bay Bridge Touchdown Focus Area.

Critical inundation pathways connect shoreline inundation areas to the inland inundation areas, providing the necessary hydraulic connectivity to convey floodwaters to inland areas. One critical inundation pathway was identified within the Bay Bridge Touchdown focus area. However, recent development in the area south of the Touchdown, as well as future planned projects (e.g., Gateway Park) which include grade changes, may alter the inundation pathways in the future. Current and future grade changes in this area should be considered before developing adaptation strategies south of the Touchdown.

Inland inundation areas are not directly on the shoreline and require a hydraulic pathway to convey floodwaters from the Bay to the inland area. These areas are the least likely to experience the full extent of temporary flooding depicted in the inundation maps due to the typical duration of a coastal storm surge event and volume of water that would be required to fill these expansive low-lying areas during an episodic event. To determine the exact extent of inland flooding or permanent inundation, more sophisticated modeling is required; however, the exposure of these areas to potential inundation and flooding is well represented by the inundation maps for the purposes of this study. Two inland inundation areas were identified within the Bay Bridge Touchdown focus area.

COLISEUM FOCUS AREA

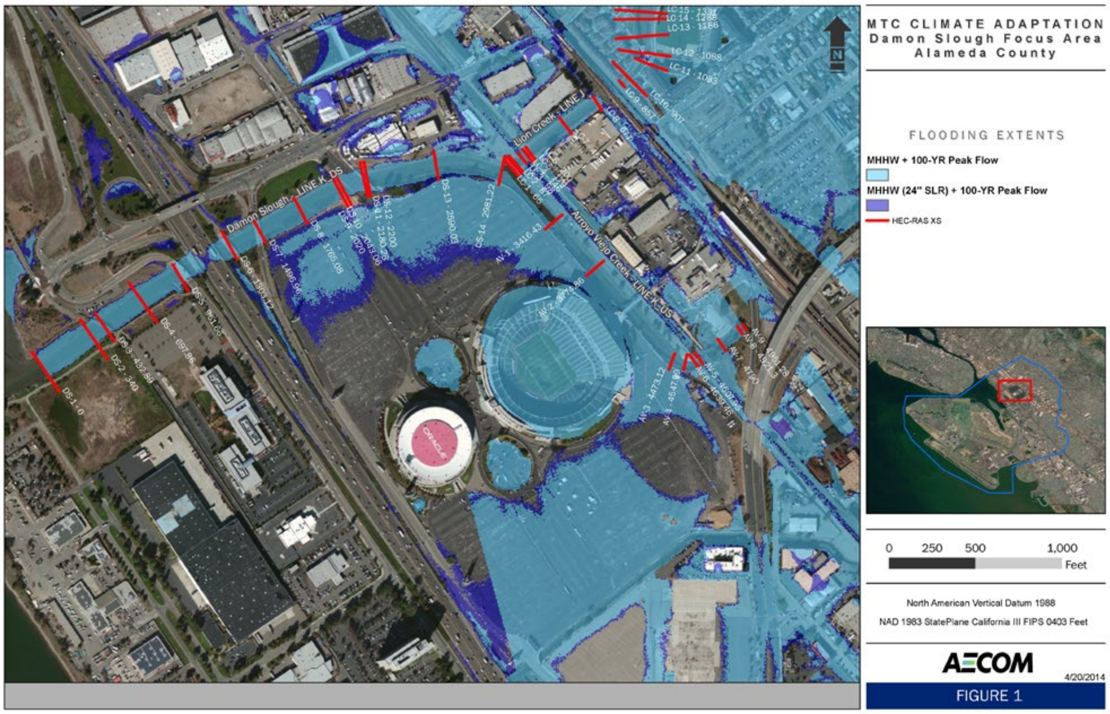
Within the Coliseum Focus Area, several important assets were identified as vulnerable to riverine flooding in addition to inundation by sea level rise and coastal storm surge. These assets are located in the vicinity of Damon Slough and the surrounding tributaries (Arroyo Viejo Creek and Lion Creek), and as a result an additional analysis of the combined impact of riverine flooding and coastal storm surge scenarios in this immediate area was conducted. This analysis leveraged an existing steady-state Hydrologic Engineering Center – River Analysis System (HEC-RAS) hydraulic and hydrologic model of Damon Slough, Arroyo Viejo Creek, and Lion Creek from the Alameda County Flood Control and Water Conservation District (ACFCWCD). The HEC-RAS model was used to evaluate various combinations of downstream Bay water levels, sea level rise, and peak flow events in the slough and creek channels to help understand the key thresholds that can result in overbank flow and inundation within the focus area (See Table IV). Peak flow events refer to high water levels in the creeks and slough with specific return periods (e.g., 1-, 5-, 10-, 25-, 50-, and 100-year). See Section 3.2 for full details of the mapping effort.

Table IV: Mapped HEC-RAS Simulations

MAPPING SCENARIO	MODELED SCENARIO
Mapping Scenario 1	MHHW + 100-year Peak Flow
	MHHW + 24-inch SLR + 100-year Peak Flow
Mapping Scenario 2	10-year Extreme Tide + 10-year Peak Flow
	10-year Extreme Tide + 24-inch SLR + 10-year Peak Flow
Mapping Scenario 3	10-year Extreme Tide + 100-year Peak Flow
	10-year Extreme Tide + 24-inch SLR + 100-year Peak Flow
Mapping Scenario 4	100-year Extreme Tide + 10-year Peak Flow
	100-year Extreme Tide + 24-inch SLR + 10-year Peak Flow

Although fifteen combinations of Bay water levels, sea level rise, and riverine peak flows were analyzed, only eight scenarios were mapped for illustrative purposes, as presented in Table II. There were limited differences observed on the maps between 12- and 24-inches of SLR, therefore only the existing conditions and 24 inches of SLR scenarios were mapped to compare the differences in flooding extent. An example of one of the maps (showing Mapping Scenario 1) is shown in Figure II (a full page version can be found in Section 3.2.2).

Figure II: Mapping Scenario 1



HAYWARD FOCUS AREA

Ten key areas of vulnerability were identified within the Hayward focus area based on a detailed review of the inundation mapping. Timing of inundation and proximity to important assets were the fundamental criteria used to select these areas, which are identified in Figure III and labeled letters “A” through “J.” These areas can be grouped into three categories—*shoreline inundation areas*, *critical inundation pathways*, and *inland inundation areas,* as in the Bay Bridge Focus Area. In both figures, shoreline inundation hazard areas are labeled in red (A-D), critical inundation pathways in orange (E-F), and inland inundation areas in yellow (G-J). Figure IV shows a general overview of the sources of flooding and the pathways that allow floodwaters to progress inland. It should be noted that the drainage in this area is complicated and not well understood, particularly the interconnections between the above- and below-ground highway drainage system and adjacent areas. In addition, the response of the drainage system to rising sea levels and potential impacts to the adjacent areas is not known. A better understanding of the drainage pathways and the interconnections between the different areas is required to develop effective adaptation strategies for this focus area.

Discussion of the Hayward focus area has been subdivided into three regions based on the flooding patterns within the focus area that occur with less than 36 inches of SLR: the area north of SR 92 (North); the area at and adjacent to SR 92 (SR 92); and the area south of SR 92 (South).

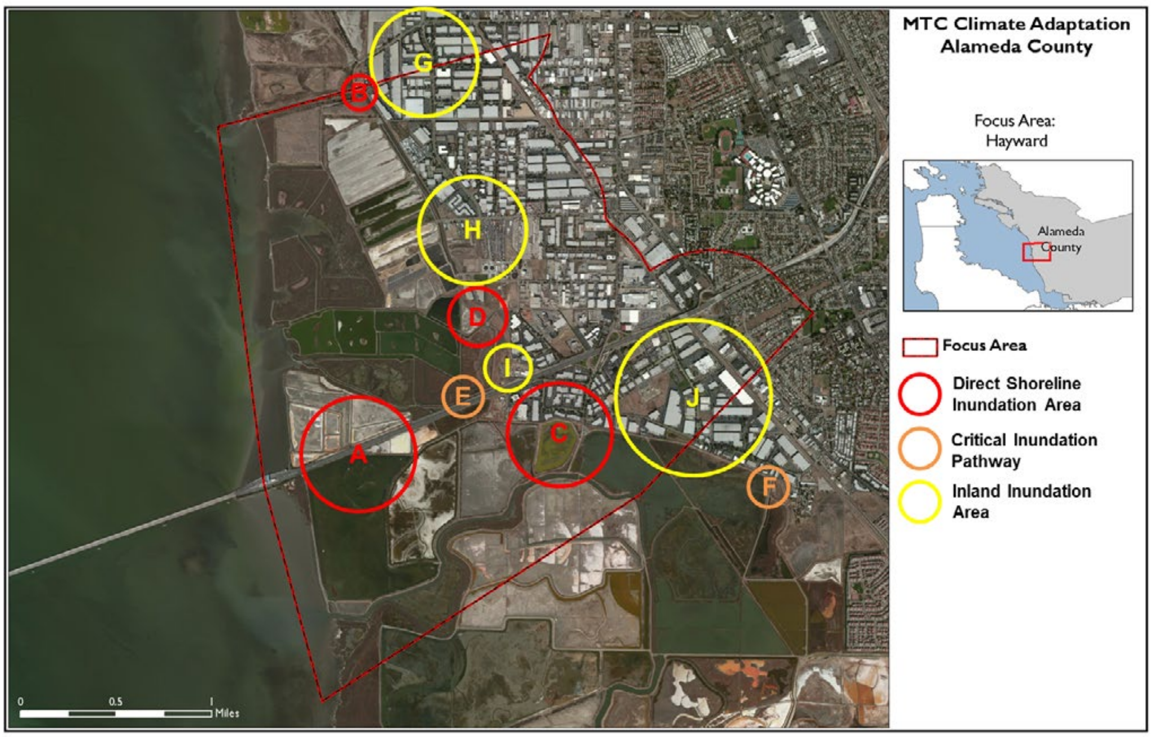
There are eight distinct marsh areas or ponds within the Hayward focus area, and these areas are separated by a network of internal and bayfront berms. The majority of this system is part of the Hayward Regional Shoreline, with the exception of Eden Landing Ecological Reserve, which is part of the Eden Landing system owned by the California Department of Fish and Wildlife. Mapping studies show scenarios that could result in inundation throughout the system, as well as the critical segments that will be overtopped, thereby inundating the adjacent area(s). Triangle Marsh, Cogswell Marsh, Hayward Area Recreation and Park District (HARD) Marsh and Eden Landing Ecological Reserve are directly connected to the Bay by natural and/or engineered inlets and are actively flooded under existing conditions.

North of SR 92, the primary sources of inundation are from natural and engineered flood control channels that are overtopped. One shoreline inundation area (Area B) was identified in this region as well as two inland inundation areas. Inundation of SR 92 and adjacent areas occurs primarily from overtopping of non-engineered berms along Oliver Salt Ponds, HARD Marsh, and Salt Marsh Harvest Mouse Preserve. (See Figure III and Figure IV).Two shoreline inundation areas (Areas A and D) were identified in this region. Additionally, a critical inundation pathway (Area E) results in inundation of inland areas (Area I).

Adjacent to SR 92, inundation occurs primarily due to overtopping of non-engineered berms east of the Eden Landing Ecological Reserve. One shoreline inundation area (Area C), one critical inundation pathway (Area F), and one inland inundation area (Area J) were identified in this region.

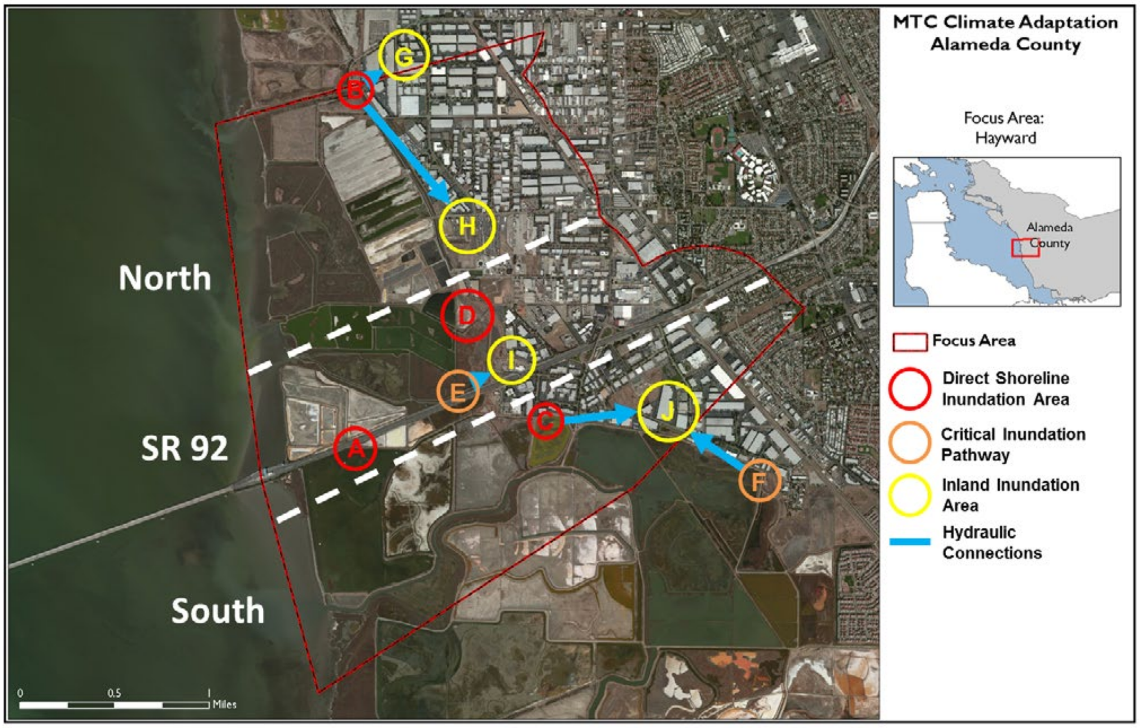
This extensive area along Arden Road and Trust Way is exposed due to overtopping of non-engineered berms at Area C and overtopping of the critical inundation pathway at Area F. Full details of the vulnerability of this focus area can be found in Section 3.4.

Figure III: Hayward Focus Area Site Location Map and Inundation Areas



Note: Circles are used to indicate approximate locations and extents of inundation. Circle sizes do not correspond to intensity, timing, or risk of inundation.

Figure IV: Delineation of Inundation Regions and Connections between Inundation Areas



RESULTS OF REFINED VULNERABILITY ANALYSIS

In addition to the inundation and flooding exposure analysis described above, physical, functional, informational, and governance vulnerabilities were identified for each of the core and adjacent assets. The classifications are defined below:

- ***Informational vulnerability*** - Challenges to obtaining information necessary to understand or resolve issues
- ***Governance vulnerability*** - Governance characteristics relating management, permitting, financing and funding availability that increase vulnerability or create barriers to implementing adaptation options
- ***Functional vulnerability*** - Functional aspects of an asset that make it very sensitive to impacts or severely limit the region's adaptive capacity
- ***Physical vulnerability*** - Physical aspects of an asset that make it very sensitive to impacts or severely limit its adaptive capacity

Both the original and the refined description of the vulnerabilities for each asset and its components can be found in the compendium of adaptation strategies in Appendix C, organized by focus area.

ADAPTATION STRATEGY DEVELOPMENT (CHAPTER 4)

A compendium of 124 adaptation strategies were developed for assets and asset components on the basis of the vulnerabilities identified in the previous stage of this project. The strategies were organized into the following three broad categories:

- Core Asset Strategies - to manage or mitigate specific core asset vulnerabilities within each of the three focus areas
- Focus Area-wide Strategies - to manage or mitigate core and adjacent asset vulnerabilities through implementation of a large-scale intervention (e.g., shoreline protection) within each of the three focus areas

- Agency-specific Strategies - to manage or mitigate internal agency management-related and information-related vulnerabilities (applicable across all focus areas)

Within each of these strategy categories, sub-categories were created, in order to clearly identify what type of vulnerability the strategy was addressing. The sub-categories, organized by the type of vulnerability which the strategy addressed, are listed below, along with an example of each.

- Physical Strategies: Strategies that address physical vulnerabilities of assets
    - Example: The construction of a levee on both sides of a highway segment to prevent physical damage to the segment
- Functional Strategies: Strategies that address the functional vulnerabilities of assets
    - Example: Investigation and establishment of alternative truck routes to ensure continuity of goods movement.
- Informational Strategies: Strategies that provide improved understanding of the vulnerabilities of assets arising from a current lack of information
    - Example: Conducting a saltwater and groundwater modeling study to understand the impact of sea level rise on local groundwater hydrology in the Bay Bridge and Coliseum focus areas
- Governance Strategies: Strategies that address governance-related vulnerabilities of assets
    - Example: Convening a working group of multiple agencies to collaboratively address climate change-related vulnerabilities to infrastructure owned and operated by the agencies

For each of the strategies included in the compendium, in addition to the strategy name and description the following information is provided (see Appendix C for full listing of the strategies):

- Assets protected by strategy
- Vulnerabilities addressed by strategy
- Point of intervention
- Partners
- Timing

This compendium of strategies can potentially serve as a resource, not just for the transportation assets that were evaluated in this project, but also for transportation assets regionally and nationwide.

Following the initial identification of strategies, a prioritization process was used to select a final list of 5 strategies for more detailed development. The prioritization process consisted of the following two intermediate steps:

- A screening exercise to identify a short-list of 17 strategies from the master-list of 124 strategies
- A qualitative assessment to identify the final 5 strategies from the short-list of 17 strategies

SCREENING QUESTIONS

The following questions were used to help screen the 124 strategies down to 17 for more detailed evaluation (further detail can be found in Section 4.3.1). Given the multi-agency collaborative nature of this pilot, strategies with multiple co-benefits applicable to multiple areas and requiring agency collaborations were prioritized.

1. Does the strategy address the vulnerability of multiple assets?
2. Does the strategy address multiple vulnerabilities of an individual asset (informational, governance, functional, physical)?
3. Does the strategy require significant multi-agency coordination to be effective?

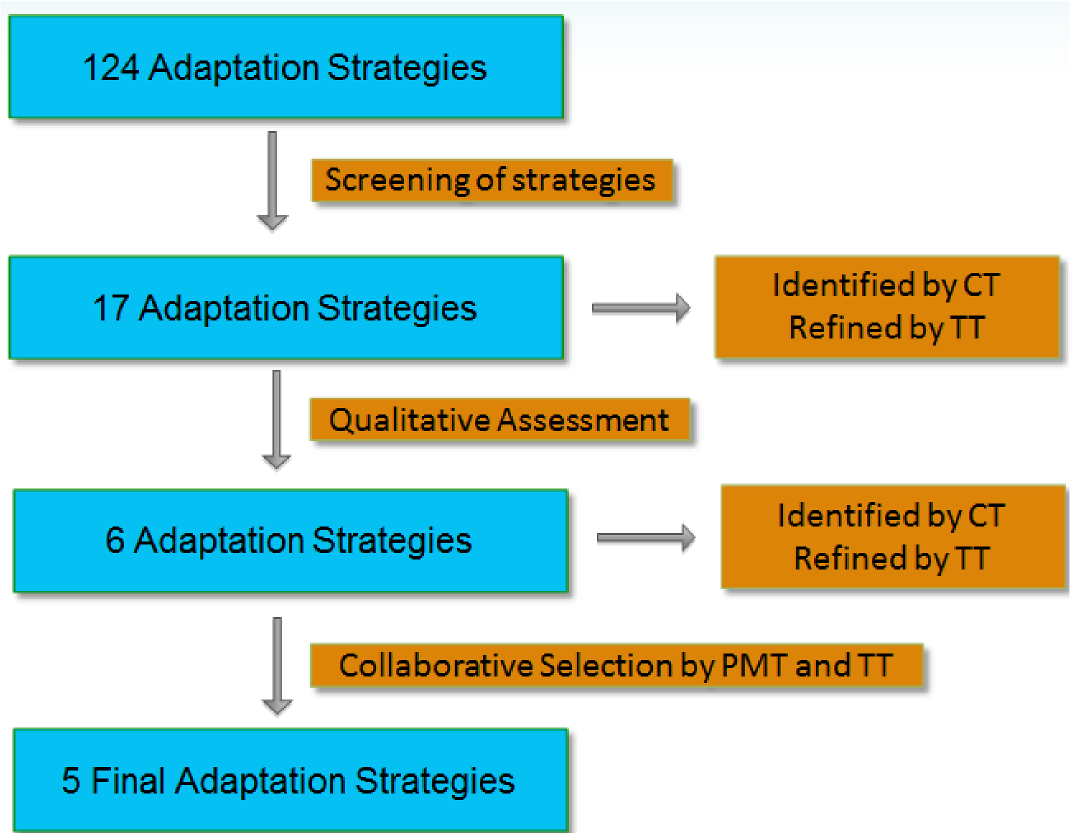
4. Can the strategy be used by more than one agency?
5. Does it make sense to start working on this strategy in the next 5 years?
6. Does the strategy address multiple transportation modes?
7. Does the strategy accomplish or contribute to other critical operational objectives (congestion management)?
8. Does the strategy reduce consequences (impacts) on society/equity?
    a. Homes
    b. Places of work
    c. Recreation areas
9. Does the strategy provide a positive impact on the environment?
    a. Habitat or biodiversity?
    b. Water quality?
10. Does the strategy provide a positive impact on the economy?
    a. Goods movement?
    b. Commuter movement?

QUALITATIVE ASSESSMENT

In this step, the 17 adaptation strategies short-listed in the screening exercise (see Section 4.3.1.2) were evaluated further via a qualitative assessment. A set of criteria was developed for the qualitative assessment in order to allow a comparison of the financial, social, environmental, and administration-related performance of the 17 strategies. A qualitative ordinal ranking system was used for most of the criteria to remove false precision of estimated performance metrics. Each criteria category (i.e. financial, social, environmental, and governance-related) was weighted equally in terms of its contribution to the overall favorability of a strategy. While the analysis was essential to the process, the goal was not to necessarily select the highest scoring strategies, but also to evaluate the trade-offs between the different criteria categories, and to select strategies that were the most balanced in terms of meeting criteria in all four categories and covering all three focus areas. Some strategies were also important precursors to others (such as undertaking a drainage study before being able to identify the most appropriate location for raising a berm). In addition, some high scoring strategies did not need further evaluation before the client team to take them on, or they could immediately be added to forthcoming projects, such as the update to the Regional Transportation Emergency Management Plan. Further detail and the full list of strategies can be found in Section 4.3.

Based on the results of the qualitative assessment, a final list of five adaptation strategies was selected from the short-listed 17 strategies identified in the screening exercise. The five strategies included at least one strategy for each focus area and at least one strategy for each vulnerability type. Figure V shows the overall process that was used to select five strategies from the original list of 124 strategies.

Figure V: Strategy Selection Process



CT stands for Consultant Team
TT Stands for Technical Team
PMT stands for Project Management Team

The final strategies selected were:

- Bay Bridge Focus Area – Artificial dunes (Note this strategy was later changed to a living levee)
- Bay Bridge Focus Area – Offshore breakwater
- Coliseum Focus Area – Damon Slough living levee
- Hayward Focus Area – State Route 92 drainage study
- Agency Specific – BART Planning Process Update (Note this strategy was later renamed to *Mainstreaming climate change risk into transportation agencies* to expand its relevance to all transportation agencies)

BASELINE SCENARIOS

Baseline scenarios were future scenarios developed for each focus area to show how the identified vulnerable assets and asset components in each focus area would be affected by various magnitudes of SLR and storm surge, and how the affected assets and components would have broader impacts on mobility, society, and the environment if no actions are taken to adapt to these climate change variables. The baseline scenario for each focus area was determined based on the minimum projected level of inundation that would first affect key transportation assets in the focus area, and cause disruption to these assets. The baseline scenarios were then used to evaluate the effectiveness of the five final adaptation strategies, by comparing the expected performance of the adaptation strategies against the baseline scenarios for each focus area. Note that inundation depths associated with the baseline scenarios were used in this comparison, rather than the time of onset of inundation (e.g., 2030, 2050, or 2100), given the uncertainties associated with the onset of permanent inundation and the vulnerability of assets to the same inundation depths under different combinations of sea level rise and storm surge events. See Section 3.1 for more detail on this approach to the onset of inundation, also noting that according to the NRC, the Bay could rise by 12 to 24 inches by mid-century and by 36 to 66 inches by the end of the century.

BASELINE SCENARIO FOR BAY BRIDGE FOCUS AREA

The baseline scenario that was selected for the Bay Bridge focus area was the MHHW +36-inch scenario. This level of inundation could occur today under a 50-year storm surge event, and is below the FEMA 100-year base flood elevation. It was found that this baseline scenario results in inundation across the westbound lanes of the I-80 approach, the westbound portion of the toll plaza, the Emeryville Crescent tidal wetland, Radio Beach, three radio towers and associated facilities, and several partially paved access roads.

BASELINE SCENARIO FOR COLISEUM FOCUS AREA

The baseline scenario that was selected for the Oakland Coliseum Focus Area was the MHHW +48-inch scenario. Under this scenario, significant inundation of critical assets occurs. This focus area is vulnerable to flooding from both coastal storm surge and riverine flooding; therefore multiple scenarios could result in the same, or similar, level of inundation. Under existing conditions (i.e., today), a similar level of inundation would occur with a 100-year storm surge event coupled with a 10-year riverine flood event, or during a 10-year storm surge event coupled with a 100-year riverine flood event (both scenarios could occur today during a strong El Niño winter storm). It is important to note that a 100-year storm surge event does not imply that this scenario could only occur once every 100 years; a 100-year event has a 1% chance of occurring in any given year, and it can occur multiple times within a 100-year timeframe. The level of inundation associated with the baseline scenario is also similar to that which occurs with 24-inch of sea level rise combined with a 10-year storm surge event and a 10-year riverine flood event.

Although lesser events can result in significant flooding within the Oakland Coliseum Focus Area (see Appendix B), the selected baseline scenario results in the first direct impacts to I-880, the BART station, Amtrak station, and other assets. Although the BART station would temporarily close when the area is flooded, the BART system would remain operational (i.e. BART trains would not stop at this station, but would continue running), but system-wide delays would still likely occur.

BASELINE SCENARIO FOR HAYWARD FOCUS AREA

The baseline scenario that was selected for the Hayward Focus Area was the MHHW +48-inch scenario. This scenario results in inundation along the westbound lanes of SR 92 near the bridge touchdown area. This level of inundation is comparable with what occurs under existing conditions (today) under a 500-year storm surge event (an event with a 0.2% chance of occurring in any given year). This same level of inundation would also occur with 6-inch of SLR and a 100-year storm surge event, or with 12-inch of SLR and a 50-year storm surge event. However, this area is also vulnerable to flooding due to rainfall-runoff conditions; therefore a similar level of inundation could occur under lesser storm surge events (i.e., smaller than the 100-year event) coupled with rainfall events. The combinations of SLR, storm surge, and rainfall-driven flooding were not evaluated for this focus area, but a comprehensive drainage assessment has been proposed as the first step in adaptation strategy development. This assessment is required before developing effective physical adaptation strategies for this area.

It was found that the baseline inundation scenario results in the inundation of 3 of 5 lanes of SR 92 West, 2 of 3 lanes of SR 92 East and part of Eden Landing and Arden Road.

ADAPTATION STRATEGIES (CHAPTERS 5-8)

Five strategies, as identified through the process described earlier, were developed, including descriptions, conceptual sketches (if appropriate), order of magnitude construction, and operations and maintenance costs, partners and regulatory issues. A summary of each strategy is outlined below.

BAY BRIDGE TOUCHDOWN ADAPTATION STRATEGIES (CHAPTER 5)

The Bay Bridge touchdown focus area is located south of Emeryville, along the northern boundary of the Oakland Outer Harbor. Several vulnerable assets are expected to be inundated under the MHHW +36-inch scenario, including the westbound portion of the toll plaza, westbound lanes of the I-80 approach, the Emeryville Crescent tidal wetland, Radio Beach, three radio towers and associated facilities, and several partially paved access roads. Many stakeholders have active interests in this focus area including the California Department of Transportation (Caltrans), Bay Area Toll Authority (BATA), California Transportation Commission (CTC), the San Francisco Bay Conservation and Development Commission (BCDC), the East Bay Regional Park District (EBRPD), the City of Oakland, the Port of Oakland, the East Bay Municipal Utility District (EBMUD), the Association of Bay Area Governments' (ABAG) Bay Trail Project, and the Metropolitan Transportation Commission (MTC). Together, these agencies comprise the Gateway Park Working Group (GPWG).

Following the selection process described earlier, a living levee[10] and offshore breakwater were selected as a pair of complementary strategies to help protect the vulnerable assets in the focus area (See Figure VI and Figure VII respectively).

The living levee is designed to protect against flooding from at least a mid-century sea level rise magnitude coupled with a 100-year extreme tide event, the water elevation of which is greater than the baseline scenario elevation of MHHW+36-inch SLR for the Bay Bridge touchdown focus area. The design includes freeboard to meet the requirements for FEMA accreditation, protect against wave overtopping, and be adaptable to accommodate higher SLR magnitudes. The crest of the levee would serve as an access road to replace the current road that is anticipated to be inundated. The relatively flat seaward slope of the levee includes vegetation plantings and is designed to provide both intertidal and upland marsh habitat that is expected to be lost due to SLR. For higher SLR scenarios, the current design elevations can be feasibly increased or the levee itself can be constructed to a higher elevation at a future date. To increase the height of the levee at a future date, one option would be to excavate material from the outer layer of levee in order to strengthen and adapt the levee core to accommodate a greater levee height. Future adaptation potential can be built into the levee design if this approach is desired.

The offshore breakwater is designed to protect against increased wave overtopping and wave-induced erosion along the shoreline that is expected to come with SLR. The design factors in 36 inches of SLR and will protect against a 25-year design wave. It is proposed that the breakwater be placed northwest of Radio Beach to protect the proposed levee from overtopping and erosion. Although the breakwater will greatly reduce wave heights in this area, it was designed to preserve a fraction of the wave energy so that sediment transport and other important geomorphological characteristics of the beach and tidal marsh will be maintained for as long as possible. For higher SLR or wave scenarios, the current design elevations can be increased or the breakwater itself can be constructed to a higher elevation at a future date.

[10] Note that an artificial dune was first identified as a potential strategy to pair with the breakwater, however after initial analysis, a living levee was identified as more appropriate for this location. A living levee is a structure which couples multiple benefits, including flood protection and habitat restoration or creation. Typical flood protection levees do not incorporate "living" or vegetated elements; whereas a living levee seeks to maximize the inclusion of vegetation in order to create valuable habitats and create habitat corridors which can link critical habitat areas together. Living levees can be found in both coastal and riverine environments.

Applying these strategies in combination will protect vulnerable sites from inundation and flooding as identified from the inundation mapping, wave overtopping and wave-induced erosion, and will create natural marsh habitat to mitigate for areas of beach and marsh expected to be lost.

DAMON SLOUGH ADAPTATION STRATEGY – LIVING LEVEE (CHAPTER 6)

The Coliseum focus area is located inland of the Martin Luther King, Jr. Regional Shoreline of San Leandro Bay in Oakland, California. The area includes key transportation assets, including the I-880 Damon Slough Bridge, the Oakland Coliseum Bay Area Rapid Transit (BART) Station, the Oakland Coliseum Capitol Corridor/Amtrak Station, the Union Pacific rail mainline, and the new Oakland Airport Connector. The area also includes key commercial assets such as the Coliseum Complex[11] (which contains the Oakland Coliseum and the Oracle Arena). Many agency stakeholders have active interests in the focus area. These include the San Francisco Bay Conservation and Development Commission (BCDC), Metropolitan Transportation Commission (MTC), the city of Oakland, Caltrans, Amtrak, Union Pacific, and BART. Following the selection process described earlier, a living levee alongside each side of the slough was selected as a strategy to help protect the vulnerable assets in the focus area (Figure VIII).

Figure VI: Approximate footprint of the living levee designed to protect I-80 from at least mid-century sea level rise with a 100-year total water level

[11] It should be noted, that as of December 2014, the City of Oakland has been in the process of developing a Coliseum Area Specific Plan, the goal of which is to provide the guiding framework for reinventing the City of Oakland's Coliseum area as a major center for sports, entertainment, residential mixed use, and economic growth. One of the options that may be considered under this plan is the redesign or removal of the Oakland Coliseum Complex. <http://www2.oaklandnet.com/oakca1/groups/ceda/documents/policy/oak048826.pdf>

Figure VII: A potential breakwater placement and configuration offshore of Radio Beach that will minimize wave action and overtopping of the levee as sea level rises

The living levees are designed to protect against flooding from at least a mid-century sea level rise magnitude coupled with a 100-year extreme tide event. This scenario has a water elevation greater than the baseline scenario elevation of MHHW + 48 inches of SLR for the Coliseum focus area. Both living levees are designed to include freeboard to meet the requirements for FEMA accreditation and can be adaptively managed to accommodate higher SLR magnitudes. It is proposed that one levee be constructed along the south edge of the slough to protect the Oakland Coliseum, Oracle Arena, and related facilities from inundation. An additional levee should be placed along the north edge of the slough to protect the BART, Amtrak, and other assets from inundation. The levees will also provide some protection for I-880, and the widened lower reach of Damon Slough will reduce the potential for bridge scour at the I-880 overcrossing. Additionally, the levee crests will serve as a walking and bike path to provide recreational space. The relatively flat waterside slopes of the levees include vegetation plantings and is designed to provide both intertidal and upland marsh habitat that is expected to be lost due to SLR. For higher SLR scenarios, the current design elevations can be increased or the levee itself can be constructed to a higher elevation at a future date. It should be noted, that immediately east of the Coliseum, there is limited space for a living levee, or a traditional levee, due to the need to maintain the access road adjacent to the Coliseum for maintenance/service vehicles. In this area, placement of a seawall is recommended for providing flood protection from both coastal and riverine flood sources as needed (See Figure VIII). However, if the Coliseum Complex is redesigned or removed (which may be one alternative under the Coliseum Area Specific Plan[12]), a living levee design for this reach would likely be possible.

[12] See: http://www2.oaklandnet.com/oakca1/groups/ceda/documents/policy/oak048826.pdf

Figure VIII: The layout and footprint of the living levee (brown) and the section where seawall might be necessary due to space limitations

SR 92 DRAINAGE STUDY (CHAPTER 7)

The Hayward focus area is complex, and currently the drainage pathways and the inter-relationship between the San Mateo – Hayward Bridge touchdown (SR 92) drainage systems and surrounding areas are not well understood, including the response of the drainage system to rising sea levels. Any physical adaptation strategies proposed for this area must consider the existing highway drainage system, and allow provisions for future highway drainage in a responsible and practical manner – including considerations for maintaining the drainage system as sea levels rise. An in-depth understanding of the drainage network and capacity performance is critical because additional vulnerabilities in the watershed may exist, but have not yet been identified. Therefore, a detailed drainage assessment for the SR 92 touchdown area was selected as a priority strategy to address the current informational vulnerability. This step will be the key to unlocking future actions in the focus area, including developing effective strategies that address the physical and functional vulnerabilities of this region. This assessment will help identify adaptation strategies that can increase the resilience of the focus area to sea level rise and precipitation-based flooding associated with the drainage systems. These strategies will increase the resiliency of other inland assets of value – assets that would otherwise be impacted from the reduced performance of the drainage system in the face of rising sea levels.

The SR 92 strategy includes a scope to complete the drainage assessment, including an extensive analysis of areas adjacent to the SR 92 touchdown. Key tasks include: the review and documentation of existing documents and supporting analyses associated with the existing drainage systems, reviewing existing and readily available models of the current drainage network, reviewing the existing capacity of the current drainage system, and conducting a future capacity assessment to understand how the drainage system will perform under an array of potential storm conditions (i.e., several combinations of Bay water levels and rainfall runoff events). The results of the drainage assessment will be used to formulate recommendations that can support future drainage improvements and adaptation strategy development.

Coordination and active collaboration between the stakeholders and property owners will be required to develop effective adaptation strategies. The stakeholders for the SR 92 touchdown strategy include

Caltrans (the owner and agency responsible for operations and maintenance of the SR 92 bridge), the City of Hayward, the Metropolitan Transportation Commission (MTC) / Bay Area Toll Authority (BATA), the Alameda County Flood Control and Water Conservation District (ACFCWCD), the California Department of Fish and Wildlife, the California Coastal Conservancy (SCC), BCDC, Hayward Area Shoreline Planning Agency, and East Bay Regional Park Department (EBRPD), and the Hayward Area Recreation and Park District (HARD).

The SR 92 drainage assessment is a necessary step that will provide the stakeholders and adjacent landowners with an in-depth understanding of the drainage system, and allow for the development of more robust adaptation strategies that address a wide range of vulnerabilities. Examples of adaptation strategies may include the consolidation of discharge points to a combined outfall location, or re-routing roadway drainage to more advantageous locations, coupled with physical strategies such as living levees and wetland restoration.

MAINSTREAMING CLIMATE CHANGE RISK INTO TRANSPORTATION AGENCIES (CHAPTER 8)

California Executive Order S-13-08 (2008) paints a stark picture of the potential impacts of climate change, stating that "climate change in California during the next century is expected to shift precipitation patterns, accelerate sea level rise and increase temperatures, thereby posing a serious threat to California's economy, to the health and welfare of its population and to its natural resources." The threat applies directly to transportation infrastructure and operations, which facilitate critical access to economic, educational, cultural, and social opportunities within communities and across the State. To continue fulfilling this vital function, transportation agencies must systematically manage the risks of climate change in a cost-conscious and context sensitive way.

Transportation agencies already face a variety of challenges – from congestion to safety and state-of-good repair – and have developed robust planning and decision-making processes to address needs and prioritize actions. This strategy proposes that climate change risk – as one risk among many – be managed by leveraging and occasionally adjusting existing systems and procedures, an approach referred to as *mainstreaming*. However, the challenge of climate change is potentially enormous and its full dimensions are still emerging, necessitating an integrated and coordinated approach that should involve representation across the agency. Illustrative approaches to mainstreaming, organized by the generic functional areas of Planning, Capital Development, Operations, and Administration, are offered as part of this strategy, along with a potential structure for agency and inter-agency coordination.

LESSONS LEARNED (CHAPTER 9)

This section outlines the lessons learned from the project, particularly highlighting challenges to obtaining and applying data, and assessing and selecting adaptation strategies.

DATA COLLECTION

The data collection exercise benefited from the first round MTC pilot for which a limited amount of information was collected on all the key assets under consideration. In addition, BCDC's ART project had initiated data collection efforts for each of the project's focus areas. However, despite this, the Technical Team spent considerable effort gathering more data through a survey monkey questionnaire which had 150 questions per asset and a further 50 questions per identified component of the asset. Specific component questions were required due to the answers potentially being very different depending on the different components. For example, the physical characteristics of the Toll Plaza are very different to the Temescal Creek Bridge, yet both are important components of the I-80/I-580 segment between Powell Street to the Toll Plaza.

The information was particularly hard to find for many of the adjacent assets since they are not owned or operated by the project partners; however, the information was often not available for the asset components even if owned or operated by the project partners. For this reason, many questions were left unanswered. Despite, or because of this, lots of time was spent attempting to answer the questions. However, given that ultimately adaptation strategies were only developed for 5 of the assets or asset components, much of the data was not used in detail for the project. Some of the data collected was used to inform the vulnerability assessment of each of the assets and their components (particularly the physical information) and some of it was used to inform the economic and mobility impacts of the 5 adaptation strategies. There needs to be a balance between collecting data at an early stage in the project to help decide which assets are most vulnerable and at risk and therefore need prioritization for adaptation, and then once those assets are identified, collecting further data to help develop appropriate adaptation strategies.

It is noted however, that all the information that was collected was geo-coded, whether qualitative or quantitative. It is expected that having the data recorded as a GIS attribute will be very useful for the agencies in future when the vulnerabilities of different assets are re-examined and further adaptation strategies developed.

VULNERABILITY REFINEMENT

A clear lesson learned from the first MTC pilot study was the limitation in producing maps containing a large difference in the inundations from two SLR scenarios (16-inch and 55-inch) and SLR + 100 year storm surge scenarios. This project therefore undertook a more refined analysis of potential exposure to future sea level rise. The full methodology for this new analysis is described in Chapter 3 and was a very useful tool for the project team, both in understanding timing and onset of sea level rise and how it relates to flooding from existing storm events as well as in communicating the vulnerability to stakeholders. It is highly recommended that this type of analysis be carried out in similar projects, contingent upon the availability of technical resources such as models and data.

If the sea level rise or storm surge mapping doesn't align with local knowledge of existing flooding, a thorough field visit should be carried out to verify the vulnerabilities. The shoreline overtopping assessment was very helpful at highlighting which vulnerable locations needed to be verified in the field.

The critical path analysis described in Chapter 3 was also very helpful in highlighting how the exposed areas of the focus areas become inundated or flooded – either from direct shoreline inundation, or from a critical pathway that can lead to extensive inland inundation. For the Bay Bridge location, this analysis showed that all of inland inundation on the south side of the bridge could be prevented by relatively simple physical strategies (See Appendix B.1: Bay Bridge Focus Area Technical Memorandum (2014), Section 6.2 for examples of these strategies). This allowed creative resources to be focused on developing strategies for the north side of the bridge where water was overtopping broad stretches of the shoreline.

ADAPTATION STRATEGY DEVELOPMENT AND EVALUATION

During the project it was decided that at least one adaptation strategy should be developed to address each of the vulnerabilities identified by the project team across the functional, governance, informational and physical categories. Given the number of vulnerabilities identified, this led to an exhaustive approach and the ultimate production of a compendium of 124 adaptation strategies. While it is anticipated that this compendium (see Appendix C) will be a valuable resource for the project partners and other agencies regionally and nationally, it may have been better to identify priority vulnerabilities for which to develop a more limited set of adaptation strategies rather than the broad strategy development process that was undertaken.

Given the large number of strategies developed, a two stage evaluation process was required in order to be able to narrow down the strategies to a final 5 to be further developed. Given the number of strategies to be evaluated, a qualitative list of questions was developed for the first stage through which the124 strategies could be run fairly quickly. The second stage involved a slightly more rigorous qualitative assessment, using data collected earlier in the project but not necessarily calculating further numbers. However, even this second stage assessment was not as detailed as the original evaluation process that was envisaged by the client team at the start of the project due to lack of appropriate data at this level of strategy development, particularly on costs and mobility impacts.

The team spent considerable time developing an appropriate set of questions for each stage and carrying out the 2 assessments. Ultimately the technical team over-ruled some of the conclusions reached through the evaluation process for selecting the final strategies for detailed analysis due to specific local knowledge of the assets or strategies under consideration and due to the desire to have at least one strategy in each focus area, and to have a number of the different types of vulnerability addressed. While a standardized qualitative assessment can be a good way to evaluate the performance of strategies, it should always be supplemented by the local knowledge and expertise of stakeholders and agencies.

Finally, the full set of evaluation criteria developed was only used for the final five strategies developed, and given that these strategies were addressing different assets in different locations, the results have more limited use as they cannot really be directly compared.

NEXT STEPS (CHAPTER 10)

This report has significantly enhanced the understanding of the vulnerability of certain key assets in Alameda County to sea level rise inundation across a range of scenarios. It has also proposed a number of representative strategies to help reduce these vulnerabilities that could be applicable to other areas of Alameda County as well as the wider Bay Area and beyond.

A number of the strategies (*SR 92 drainage study* and *Mainstreaming Climate Risk into Transportation Agencies*) could be taken forward now with little further research by appropriate agencies, and this report provides strong evidence to support the funding of these activities.

The physical strategies will all require further analysis and design work to ensure they are the most appropriate solutions to address future flooding from SLR and other extreme weather events at the identified sites. In addition, these strategies could also be considered for potential use at other areas along the Bay shoreline. This report can be used to support funding applications for such analysis. Recommended next steps for each of the focus area strategies are included in their respective chapters (5 and 6).

The compendium of 124 strategies should be reviewed by the agencies, and strategies adopted that could be relatively easily incorporated into existing day-to-day practice (such as updating of design standards in relation to waterproof sealant). Other high-scoring strategies should be identified for further analysis. There were several informational strategies most notably the one on addressing the lack of understanding of the impact of saltwater intrusion on infrastructure, for which assistance from local (or national) academia is needed. Efforts should be made to engage with potential universities and funders of such research such as the USGS.

The report also identified a number of studies being undertaken by other agencies in the County that could improve understanding of the vulnerability of assets, such as the Alameda County Flood Control and Water Conservation District's updated HEC-RAS modelling for Damon Slough, which would improve the riverine flooding analysis of the Coliseum Focus Area. The progress of these studies and analyses should be tracked so that this update can happen in a timely manner.

Finally, the findings from this study, particularly in relation to vulnerable transportation assets and inundation flow paths, should be used to inform decisions regarding the 2017 update of the Bay Area's Sustainable Communities Strategy, Plan Bay Area.

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1.0 Introduction

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1. INTRODUCTION

The Metropolitan Transportation Commission (MTC), the San Francisco Bay Conservation and Development Commission (BCDC), the California Department of Transportation, District 4 (Caltrans) and San Francisco Bay Area Rapid Transit District (BART) have partnered on a collaborative sub-regional pilot project to assess adaptation options for a subset of key transportation assets in the San Francisco Bay Area that are vulnerable to sea level rise (SLR). This study builds on the *Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project*[13] which was completed in 2011 and identified representative critical transportation assets in the region vulnerable to SLR. Both studies were generously funded by the Federal Highway Administration (FHWA). The first was one of five pilot studies to test a conceptual framework developed by FHWA to help Departments of Transportation and Metropolitan Planning Organizations (MPOs) better understand their vulnerabilities to climate change. The framework was updated by FHWA with feedback and examples from the five pilots and released in 2012 as the FHWA Climate Change & Extreme Weather Vulnerability Assessment Framework[14]. This second study is one of 19 follow-up pilot studies nationwide that are (1) further testing the Framework, (2) developing adaptation strategies and/or (3) improving the vulnerability analyses.

The *Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project* developed detailed risk profiles for approximately 30 transportation assets including road, rail and transit in Alameda County. Having identified the risks, and in order to move from assessment to action, three focus areas in this pilot project containing ‘core’ transportation assets and ‘adjacent’ community assets were selected for further study. A set of detailed adaptation strategies has been developed to protect key bridge, highway, transit and community assets from future inundation.

In addition to the *Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project*, this study has leveraged a number of closely related adaptation planning efforts in the Bay Area:

- The Bay Area Rapid Transit Climate Change Adaptation Assessment Pilot project[15] funded by the Federal Transit Administration (FTA) and undertaken by BART with assistance from BCDC and the National Oceanic and Atmospheric Administration (NOAA) Coastal Service Center (CSC);
- The larger Adaptation to Rising Tides[16] (ART) project led by BCDC and funded in part by NOAA which looks at a wide range of community assets; and
- The Alameda County Shoreline Vulnerability Assessment undertaken by BCDC and the Alameda County Flood Control and Water Conservation District (ACFCWCD)

In addition to these vulnerability assessments, the project has also drawn from a number of other policy and technical initiatives underway or completed such as the Caltrans Guidance on Incorporating Sea Level Rise for use in the planning and development of Project Initiation Documents[17].

13 http://www.mtc.ca.gov/planning/climate/RisingTides-TechnicalReport.pdf
14 https://www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/vulnerability _assessment_framework/fhwahep13005.pdf
15 bids.mtc.ca.gov/download/519
16 http://www.adaptingtorisingtides.org/
17 http://www.dot.ca.gov/ser/downloads/sealevel/guide_incorp_slr.pdf

1.1 GOALS OF PROJECT

The project goals were to develop:

- A refined understanding of vulnerability and risk for the specified assets using existing information and targeted additional information as needed
- A refined understanding of SLR and storm event exposure in the three focus areas by analyzing the extent, depth, and pathways of inundation caused by overtopping of specific shoreline segments
- High-level climate adaptation options on three scales: (1) the core transportation assets alone, (2) the core transportation assets with key adjacent assets, and (3) each focus area as a whole
- Five refined adaptation options with specific and detailed actions including identification of timing, responsible parties, and methods for implementation
- A suite of criteria used first to select representative adaptation strategies from the long list and then second to evaluate the high-level climate adaptation strategies selected for further development.

The expected outcomes of the project were:

- An understanding of how detailed vulnerability and risk information can support asset specific adaptation options
- An analysis methodology for refining SLR and storm event exposure at the focus area scale and potentially site specific scale
- A suite of adaptation options appropriate for multiple transportation modes sensitive to surrounding land-uses, community values, ecological assets, and local economics
- Refined adaptation options which can be implemented either by the four participating partner agencies independently or in collaboration with others
- Evaluation criteria to select and prioritize adaptation actions for the current project, which serve as a framework that other adaptation projects can use.

1.2 PROJECT FOCUS AREAS

The nine-county San Francisco Bay Area, home to approximately 7 million people, is the nation's fifth most populated urban center. 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, and transit systems, that connects the shoreline communities to each other and to the rest of the region.

The National Research Council's (NRC, 2012) most recent sea level rise projections considered a range of potential sea level rise projections, considering both the rates that were most likely to occur, as well as upper and lower uncertainty bounds that were possible given the current uncertainties in some of the factors that contribute to global and local sea level rise projections. NRC (2012) suggests that it is *likely* that the bay will rise by at least 12 inches by mid-century and 36 inches by end of century; however, it is *possible* that sea levels could rise by as much as 24 inches by mid-century and 66 inches by end-of-century. This means that today's floods will be the future's high tides and areas that currently flood every 10–20 years will flood much more frequently. Neighborhoods, businesses, and entire industries that currently thrive on the shoreline will be subject to this flooding. These shoreline areas in the bay are home to more than 250,000 residents who will be directly affected and many others, including workers, who will be indirectly affected by reduced access to important services, such as transit and commercial centers, health-care facilities, and schools[18].

For the first FHWA pilot project, a competitive process was used to select the southern portions of the Alameda County shoreline (stretching from Emeryville in the north to Union City in the south) as the Bay Area sub-region to be assessed. The Alameda County sub-region provided the most comprehensive submittal and included interest from the cities of Oakland, San Leandro, Hayward and San Lorenzo, the county, East Bay Regional Park District (EBRPD), Bay Trail and other partners. The shoreline of the sub-region is diverse, including airports, seaports, industrial and residential areas, parks and natural systems. The sub-region also contains a large amount of regionally significant transportation infrastructure including freight and passenger rail, interstate highways, two vulnerable bridge touchdowns, the Oakland airport and seaport and elements of the BART network. As part of the first pilot, a series of SLR inundation maps were developed for mid (16-inch) and end of century (55-inch) scenarios, with and without the impacts of 100 year storm. These maps were used, alongside sensitivity and adaptive capacity criteria to identify the assets in the project area most highly vulnerable to sea level rise. Almost thirty risk profiles were developed, representing road, transit, rail, facility, and community assets. For this second pilot, three focus areas were selected for study within the ART Alameda County sub-region based on their vulnerability and risk. The three focus areas are:

- The San Francisco-Oakland Bay Bridge Peninsula – 'Bay Bridge Touchdown Focus Area'
- The Oakland Coliseum Area – 'Coliseum Focus Area'
- The State Route 92 Corridor – 'Hayward Focus Area'

The locations of these focus areas are shown in Figure 1-1. The three focus areas include a confluence of major regional transportation assets and are interwoven with other important regional and community assets. The transportation infrastructure in the three focus areas includes assets critical to the region's mobility and economy, such as multimodal hubs,I-80, I-880, State Route (SR) 92, two critical bridges – the San Francisco-Oakland Bay Bridge (I-80) and the San Mateo-Hayward Bridge (SR 92), arterial and collector streets, BART (stations, track and infrastructure), and passenger and freight rail lines. These transportation assets are surrounded by a diversity of land use and community assets, including a wastewater treatment plant (WWTP), regional parks and neighborhood businesses among others, that can experience co-benefits from adaptation strategies. One of the focus areas (the Coliseum Focus Area) also includes a Priority Development Areas (PDA), where the anticipated housing and job growth is expected to occur as identified in Plan Bay Area, the San Francisco Bay Area Sustainable Communities Strategy (SCS) / Regional Transportation Plan (RTP) required by State and federal law. The RTP/SCS describes land use development patterns and transportation investments intended to reduce greenhouse gas emission by better aligning new development with the transportation network including existing and planned high quality transit.

[18] Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November, 2011 http://www.mtc.ca.gov/planning/climate/RisingTides-TechnicalReport.pdf

Figure 1-1: Sub-regional Maps Identifying the Three Focus Areas

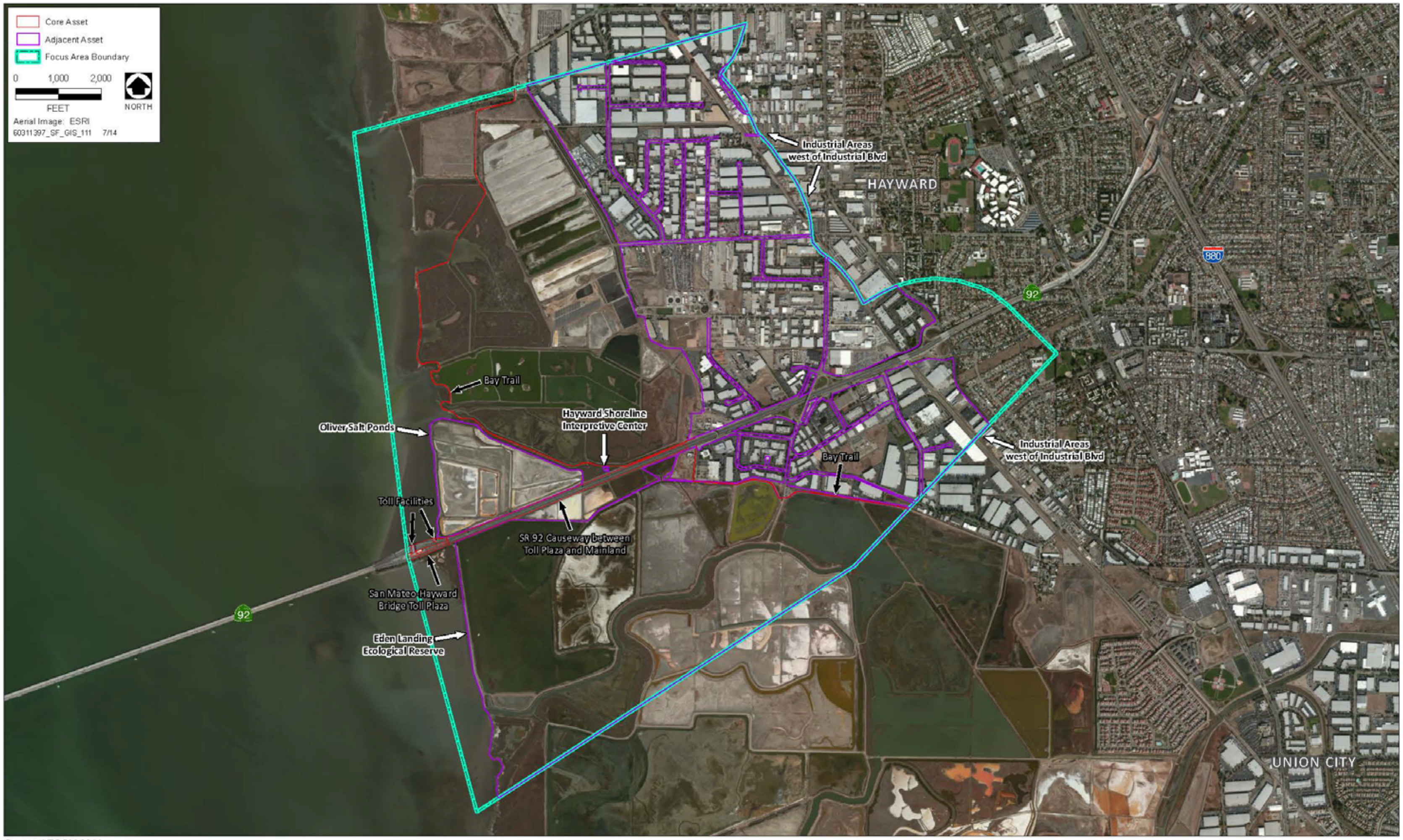
Figure 1-1a: Bay Bridge Touchdown Focus Area

Figure 1-1b: Coliseum Focus Area

Source: AECOM 2014

Focus Area: Oakland Airport/Coliseum

Figure 1-1c: Hayward Focus Area



Source: AECOM 2014

Focus Area: Hayward Shoreline

1.2.1 BAY BRIDGE TOUCHDOWN FOCUS AREA

The Bay Bridge Touchdown Focus Area is located south of Emeryville Marina in the San Francisco Bay (Bay), along the northern boundary of the Oakland Outer Harbor. The area includes the Bay Bridge touchdown and westbound toll plaza, as well as the intersection of Interstate highways I-580, I-80, and I-880. The northern portion of the focus area is mostly tidal wetlands with a small area immediately north of the Bay Bridge westbound tollbooths at Radio Beach where three radio towers are located. The core assets in this focus area are the Bay Bridge touchdown, I-880, I-80 and the BART trans-bay tube portal. Several non-transportation assets are also located within this focus area south of I-80, including a wastewater discharge transition structure and de-chlorination facilities owned and operated by the East Bay Municipal Utility District (EBMUD) at the western tip of the shoreline, the main EBMUD wastewater treatment plant (WWTP) farther inland (to the east), electrical substations, the Port of Oakland seaport, and several other industrial buildings, temporary and permanent, of which some have historical value. The proposed site for Gateway Park is also within this focus area.

The area north of the Bay Bridge touchdown is a tidal wetland which experiences regular tidal inundation under existing conditions. Approximately one third of the shoreline has some degree of rock protection. South of I-80, the Port of Oakland berths 7 through 10 are constructed of concrete and elevated several feet above typical high tides. Along the western portion of the focus area, engineered rock protection exists along the majority of the shoreline and some tidal inundation occurs under existing conditions in low-lying areas along the shoreline. The refined vulnerability assessment concentrated on the northern part of the focus area, as did subsequent adaptation strategy development. Table 1-1 lists core and adjacent assets in this focus area.

Table 1-1: Bay Bridge Core and Adjacent Assets

CORE ASSETS	ADJACENT ASSETS
I-880; 7th Street to 40th Street (Bay Bridge Touchdown) • Tributary Drainage Areas (storm drain system) I-80; 40th Street to Powell Street (Bay Bridge Touchdown Core) • Bay Bridge Toll Plaza • Temescal Creek Bridge • Tributary Drainage Areas (storm drain system) East end of BART Transbay tube including Track Portal • Redacted for Security Sensitive Information (SSI) purposes	Eastshore State Park / Emeryville Crescent EBMUD Main Wastewater Treatment Plant (WWTP) EBMUD De-chlorination and Discharge Facilities (Burma Road) Electrical Substation (Burma Road)

1.2.2 COLISEUM FOCUS AREA

The Oakland Coliseum Focus Area is located inland of the Martin Luther King, Jr. Regional Shoreline of San Leandro Bay in Oakland, California. Important assets in this area include the Oakland Coliseum BART station, the Oakland Airport BART connector, the Oakland Coliseum Amtrak Station, Union Pacific rail mainline, I-880 segments and the Oakland Coliseum Complex[19]. The shoreline is characterized by intermittent salt marshes and mudflats, rip-rap, and vegetated banks. There are a number of sloughs and creeks in the area which increases the vulnerability to flooding. Damon Slough drains directly into San Leandro Bay, and is fed by its upstream tributaries Arroyo Viejo Creek and Lion Creek. The tributaries drain portions of the vast Oakland hills through a complex storm drain system comprised of engineered

[19] It should be noted, that as of December 2014, the City of Oakland has been in the process of developing a Coliseum Area Specific Plan, the goal of which is to provide the guiding framework for reinventing the City of Oakland's Coliseum area as a major center for sports, entertainment, residential mixed use, and economic growth. One of the options that may be considered under this plan is the redesign or removal of the Oakland Coliseum Complex. http://www2.oaklandnet.com/oakca1/groups/ceda/documents/policy/oak048826.pdf

channels and hydraulic conveyance structures. Arroyo Viejo Creek daylights just upstream of the Amtrak/Union Pacific rail crossing and Lion Creek daylights north of Lucille Street near Greenman Field. Damon Slough, Arroyo Viejo Creek, and Lion Creek are all channelized and surrounded with highly urbanized and paved areas. Table 1-2 lists core and adjacent assets in this focus area. Please note that although the Oakland International Airport is a key transportation asset in the Coliseum Focus Area, it is excluded from this study, as it is already part of the Oakland International Airport/Bay Farm Island Focus Area Shoreline Resilience Planning Project[20] being led by ABAG and BCDC.

Table 1-2: Coliseum Focus Area Core and Adjacent Assets

CORE ASSETS	ADJACENT ASSETS
I880 segments • Damon Slough Bridge • Elmhurst Creek Bridge • Tributary Drainage Areas (storm drain system) Coliseum Amtrak Station Union Pacific Rail Mainline Coliseum BART Station • Traction power substation • Train control room • Pedestrian tunnel BART Airport Connector • Wheelhouse • underpass section	MLK Regional Shoreline from East Creek Slough to Arrowhead Marsh to Doolittle Drive San Leandro Channel Edgewater Drive commercial/industrial San Leandro Street Coliseum Arena Complex

1.2.3 HAYWARD FOCUS AREA

The Hayward Focus Area is located between Sulphur Creek and Alameda Creek along the eastern shoreline of San Francisco Bay. The focus area includes a significant portion of the Hayward Regional Shoreline and Eden Landing Ecological Reserve as well as the San Mateo-Hayward Bridge touchdown. The inland areas protected by the shoreline include primarily industrial land uses, with some small areas of residential and commercial uses. In addition to the San Mateo-Hayward Bridge touchdown, other important assets in this focus area include California State Route (SR) 92, the Hayward Shoreline Interpretive Center, the Oliver Salt Ponds and industrial land uses west of Industrial Boulevard.

The shoreline of this focus area is comprised of a complex of fully tidal, muted tidal and managed marshes and ponds. Bayfront and internal non-engineered berms separate the marshes, ponds, former oxidation ponds, and inland developed areas from direct exposure to the Bay (except for Cogswell Marsh and South Eden Landing Ecological Reserve, which have a natural marsh edge). This system of created and natural shorelines acts as a buffer that reduces the risk of coastal flood hazard impacts on inland developments. The non-engineered berms were created from Bay mud and fill, and although these structures are not certified or accredited flood protection structures, they do provide some level of flood protection and reduce wave hazards as they reach inland areas. Some of the berms also have integrated recreational trails that are part of the San Francisco Bay Trail system. A list of core and adjacent assets in this focus area is shown in Table 1-3.

[20] http://quake.abag.ca.gov/wp-content/documents/Airports/OAK_FocusArea_OverviewV3.pdf

Table 1-3: Hayward Focus Area Core and Adjacent Assets

CORE ASSETS	ADJACENT ASSETS
SR 92 (Hayward) • San Mateo/Hayward Bridge Toll Plaza (1st and 2nd approach) • Tributary Drainage Area (storm drain system) Bay Trail (Hayward)	Hayward Shoreline Interpretive Center Oliver Salt Ponds (HARD) Eden Landing Ecological Reserve Industrial land uses west of Industrial Boulevard

1.3 PROJECT PARTNERS

1.3.1 PROJECT MANAGEMENT AND TECHNICAL TEAM

The Project Management Team (PMT) consisted of representatives from MTC, Caltrans, BART and BCDC. The PMT provided review and guidance for the project at regular meetings. The Technical Team (TT) consisted of staff level personnel from the same four agencies who worked on a day to day basis with the Consultant Team (CT) (described below). MTC, BART and Caltrans led the data collection relating to the transportation assets and development of the transportation asset focused adaptation strategies. BCDC led the effort relating to the data collection for the adjacent and non-transportation core assets (such as the Bay Trail), the SLR inundation mapping and overtopping analysis, as well as the sharing of information about the project with stakeholders from the three focus areas who were engaged in the larger Adapting to Rising Tides (ART) project.

MTC is the transportation planning, coordinating, and financing agency for the Bay Area. It functions as both the regional transportation planning agency—a state designation—and, for federal purposes, the region's MPO. As such, it is responsible for regularly updating the Regional Transportation Plan, a comprehensive blueprint for developing mass transit, highway, airport, seaport, railroad, bicycle, and pedestrian facilities. MTC also plays an increasingly important role in financing Bay Area transportation improvements.

Caltrans, District 4 is responsible for designing, constructing, maintaining, and operating the California state highway system and the portion of the interstate highway system in the Bay Area. Caltrans released its own guidance on how to incorporate SLR into planning documents in May 2011.

BART is a rapid transit system serving the San Francisco Bay Area. The heavy-rail public transit and subway system connects San Francisco with cities in the East Bay and suburbs in northern San Mateo County. BART undertook a pilot climate adaptation assessment project in 2013, funded by the FTA[21].

BCDC is dedicated to protecting and enhancing San Francisco Bay and encouraging responsible use of the bay. It is responsible for the first 100 feet inland from the shoreline around San Francisco Bay; portions of most creeks, rivers, sloughs and other tributaries that flow into San Francisco Bay; salt ponds and managed wetlands that have been diked off from San Francisco Bay. BCDC is leading the ART project.

1.3.2 CONSULTANT TEAM

The Consultant Team (CT) was composed of transportation planners and engineers, coastal engineers and scientists, and climate change specialists from AECOM Technical Services and its sub-consultants for this project: Cambridge Systematics and Avila Associates.

21 Bay Area Rapid Transit. Climate Change Adaptation-Assessment Pilot (2013)

1.4 STRUCTURE OF THE REPORT

This report documents the full project process. It is structured as follows:

- ***Chapter 2: Data Collection***, describes the process of developing a comprehensive asset inventory
- ***Chapter 3: Vulnerability Refinement***, describes the process of developing more detailed inundation maps covering a wide range of SLR and storm event scenarios for the three focus areas, riverine flooding analysis for the Damon Slough in the Coliseum Focus Area, and the process of developing refined vulnerability descriptions for each asset by governance, informational, functional and physical categories
- ***Chapter 4: Adaptation Strategy Development and Selection***, provides an overview of the development of an initial 124 adaptation strategies, describes the prioritization process and selection of a final 5 strategies, and describes the baseline scenarios used to evaluate the effectiveness of the 5 final adaptation strategies
- ***Chapters 5 -8: Adaptation Strategies***, describe each of the five adaptation strategies selected for development including maps, sketches, photographs, tables, costs and benefits
- ***Chapter 9: Lessons Learned,*** describes lessons learned for sharing with the FHWA

The Appendices contain more detailed technical information, particularly for the inundation mapping and riverine flooding analysis.

2.0 Data Collection

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2. DATA COLLECTION

2.1 SUMMARY

This study follows the Federal Highway Administration (FHWA) Conceptual Model, a framework for conducting climate change resiliency assessments in the transportation sector. This model suggests the development of a transportation asset inventory as a preliminary step. This chapter describes the process used to collect and organize transportation asset data to support the subsequent vulnerability assessment and adaptation strategy development. The primary activities included:

- Preliminary identification of data needs and existing resources available to meet those needs;
- Development and administration of an online survey to collect information about core and adjacent assets and asset components from agency staff;
- Review and organization of survey responses to create a transportation asset inventory.

2.2 PRELIMINARY IDENTIFICATION OF DATA NEEDS AND RESOURCES

The data collection effort focused on identifying data relevant to transportation assets located in the project core and adjacent focus areas. The data needs fell into three broad categories: 1) basic data on the targeted transportation infrastructure; 2) data that characterized the transportation infrastructure use; and 3) related non-transportation data to convey the broad implications of disruptions of transportation infrastructure.

1. **Basic Data:** this information was required to understand the vulnerabilities demonstrated by the assets (and asset components) to help answer a suite of assessment questions refined from ART project assessment outputs. Vulnerability information was necessary for understanding and anticipating future risks.
2. **Data that characterizes the transportation infrastructure use:** this information was related to the populations and social infrastructure that were in proximity to the assets. This allowed consideration of both the potential costs of physical damage to, and disruption of, transportation assets, as well investigation of the potential for shared or joint solutions among transportation and non-transportation asset owners and managers.
3. **Related non-transportation data:** lastly, information was collected that would provide insight on the agencies that have ownership and/or management responsibilities for the assets, as well as the official or unofficial relationships among agencies.

The data sources included publicly available data, data from project partners (BART, BCDC, Caltrans and MTC), and data from other agencies such as Capitol Corridor, Amtrak, and East Bay Municipal Utility District (EBMUD). Two key pre-existing data sources were the Caltrans Statewide Transportation Asset Geodatabase (STAG) and the first Adapting to Rising Tides transportation pilot project funded by FHWA. Both of these sources provided transportation data available from federal, state and local transportation agencies.

2.3 DATA COLLECTION METHOD

BCDC provided initial data collection questions based on their ongoing asset vulnerability research and planning under the Adapting to Rising Tides project. Questions were then added or amended to gather additional information about each core and adjacent asset and asset component in the three focus areas.

A survey was developed to answer questions regarding asset use, condition, past performance during extreme weather events or other disruptions, and management or ownership issues.

The consultant team developed 102 asset-related survey questions (see Appendix A). The questions were organized in the following categories:

- **Governance Challenges (management/control):** Questions on management and regulation were included to determine whether an asset or asset category is vulnerable due to challenges with management, regulation, or availability of financing resources or flexibility of funding or permitting
- **Information Challenges:** Questions on information metrics were included to determine whether there are ways in which an asset or asset category is vulnerable due to deficient, incomplete, or poorly coordinated information.
- **Physical Characteristics:** Questions on physical characteristics were included to determine whether an asset or asset category may be vulnerable due to how an asset is designed or built.
- **Functional Characteristics:** Questions on functional characteristics were included to determine whether an asset or asset category is vulnerable due to dependencies and interrelationships with other assets and asset categories.
- **Consequences of Climate Change:** Questions were included on the potential consequences of climate change for an asset or asset component on society and equity, the environment and the economy to inform potential adaptation strategies.

In the survey, respondents were provided with the option of describing individual assets and up to three asset components. For example, an asset, such as a transit station, is likely to include several components, each of which may have unique vulnerability characteristics. Identifying key components was helpful in developing a focused vulnerability assessment and proposing appropriate adaptation strategies. Each asset component had a subset of 44 questions related to its governance, physical characteristics and the potential consequences of climate change (three of the question categories described above). If the respondent had more than three components to describe, this was noted in the survey and the consultant team contacted the respondent as needed to gather information on the additional components.

Once the survey questions were designed, the consultant team transferred these questions into an online survey tool called SurveyMonkey®[22]. Depending on the type of question asked in the survey, the required format types for the responses were open ended (narrative text), multiple choice (respondents could select multiple answers from a range of options), or one choice (respondents could only select one answer from a range of options). The consultant team set the response type in the question development phase, so that the response outcomes would provide the most useful and consistent datasets for future analysis and application in the project evaluation tasks.

The consultant team administered the online survey via SurveyMonkey®. This provided a flexible, easy-to-use platform that could be accessed simultaneously by multiple respondents in multiple locations. Asset representatives received an invitation to the survey via email and had approximately one month to complete the survey. The survey was designed so that multiple respondents could complete the survey in multiple sessions.

Survey respondents included all members of the project Technical Team. The Technical Team members also delegated the data collection task to colleagues within their organizations as needed.

[22] www.surveymonkey.com

2.4 CREATION OF A TRANSPORTATION ASSET INVENTORY

The purpose of the survey data review and organization task was to prepare survey responses in a manner that would be beneficial to the evaluation stage of the pilot, and serve as a resource for the partner agencies after the completion of the project. Once the survey had been completed, the following steps were carried out:

- Preliminary review and organization of survey responses
- Identification of follow-up questions and activities as necessary
- Final survey data organization
    - Sectioning the data into qualitative and quantitative responses
    - Preparation of qualitative data to be used as attributes in Geographic Information Systems (GIS) analysis. The qualitative responses provided descriptive responses about topics such as how the assets are connected to the transportation system, the formal agreements or relationships between asset managers and other parts of the system, the types of permits that might be required, or the plans for the asset or area
    - Formatting of quantitative responses for use in GIS analysis, which included information such as age and condition of assets and asset components, the costs to repair and replace infrastructure, asset use, operations, and maintenance. Questions also addressed asset and asset component vulnerability to saltwater intrusion, seismic events, or other possible events. Unique GIS fields were created to identify each new attribute data set. The team prepared the responses provided by respondents for use in GIS analysis. In some cases the responses were converted so that the format would be well aligned with GIS formatting requirements or standards. For example, some data were converted from descriptive answers to a “yes” or “no” (1 or 0, respectively) to render the response usable in GIS analysis. Table 2-1 shows the full list of assets and components for which data was collected during the survey process.

Table 2-1: Assets and Components included in the Asset Inventory by Focus Area

BAY BRIDGE FOCUS AREA	
Core Assets	**Asset components**
East end of Transbay Tube including Track Portal (Core)	Redacted for SSI
I-80/I-580 Powell Street to the Toll Plaza (Core)	Bay Bridge Toll Plaza Temescal Creek Bridge Tributary Drainage Area[23]
I-880 from 7th Street to the Toll Plaza (Core)	Tributary Drainage Area[24]
Adjacent Assets	
EBMUD Main Wastewater Treatment Plant (WWTP)	
Burma Rd. Port Operations	
Burma Rd. Electrical Substation	
Eastshore State Park / Emeryville Crescent	
COLISEUM FOCUS AREA	
Core Assets	**Asset Components**
BART Oakland Airport Connector	Rail stations (airport and coliseum) Wheelhouse or Doolittle Maintenance Facility
I-880 from Coliseum Way to 98th Avenue	Damon Slough Bridge Elmhurst Creek Bridge Tributary Drainage Area[25]
BART Station	Traction power substation Train control room A30 Tunnel
Amtrak Station and Union Pacific Rail Mainline	
Adjacent Assets	
MLK Regional Shoreline, East Creek to Arrowhead Marsh	Arrowhead Marsh
Coliseum Arena Complex	
San Leandro Street	
HAYWARD FOCUS AREA	
Core Assets	**Asset Component**
SR 92	San Mateo - Hayward Bridge Toll Plaza (1st and 2nd approach) Tributary Drainage Area[26]
Bay Trail	Johnson's Landing to Breakwater Avenue Pedestrian bridge over SR 92 SR 92 to Arden Road Parking Lot
Adjacent Assets	
Eden Landing Ecological Reserve	
Oliver Salt Ponds	
Industrial land uses west of Industrial Blvd	
Hayward Shoreline Interpretive Center	

23 There are five separate tributary drainage areas along I-80/I-580 between the Toll Plaza and Powell Street with storm drain systems to drain water from the freeway

24 There are five separate tributary drainage areas along I-880 between 7th Street and the Toll Plaza with storm drain systems to drain water from the freeway.

25 There are three separate tributary drainage areas along I-880 between the 66th Avenue and 98th Avenue with Caltrans operated storm drain systems to drain water from the freeway.

26 There is one tributary drainage area along SR-92 that starts just west of the toll plaza and ends east of the Hayward Shoreline Interpretive Center with storm drain systems to drain water from the freeway.

3.0 Vulnerability Refinement

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3. EXPOSURE AND VULNERABILITY REFINEMENT

This chapter summarizes each of the steps undertaken to refine the exposure and vulnerability analysis of assets and their components related to SLR. Section 3.1 describes the refined sea level exposure analysis in each of the focus areas. Section 3.2 describes the additional riverine flooding analysis undertaken for the Coliseum Focus Area. Sections 3.3, 3.4 and 3.5 summarize, by focus area, the assets that were found to be exposed based on a review of the inundation maps. Full details on the exposure analysis for each focus area can be found in Appendix B. Finally, Section 3.6 provides details of vulnerabilities (focusing on sensitivity and adaptive capacity) summarized for each asset.

3.1 SLR AND STORM SURGE MAP DEVELOPMENT FOR THE THREE FOCUS AREAS

The first MTC pilot study, *Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, 2011*[27] identified the exposure of the three focus areas to two SLR scenarios (16-inch and 55-inch) as well as a 100-year storm surge and a wind-wave scenario. However, as there are large differences between the inundations for these two SLR scenarios, a more refined analysis was undertaken of potential exposure to future sea level rise for this study. There is a clear distinction between the terms “permanent inundation” and “temporary flooding” used here. “Permanent inundation” occurs when an area is exposed to regular daily tidal inundation. A permanently inundated area can no longer be used in the same way due to the frequency of its exposure to sea water. In contrast, “flooding” occurs when an area is exposed to episodic, short duration inundation caused by storm events or extreme tide events of greater magnitude than normal tide levels. Inland areas may be temporarily flooded during an extreme tide event while maintaining at least a portion of their functionality once the floodwaters recede. However, sensitive assets may suffer irreversible damage if exposed to any amount of water, even temporarily. The term flooding, as it is used throughout this report, is therefore a temporary condition that results from a storm event or extreme tide events rather than the permanent inundation due to daily high tides.

To assess portions of the three focus areas that are exposed to inundation and flooding, six scenarios were examined (Table 3-1). The scenarios were developed by adding different amounts of SLR onto the elevation of the existing conditions daily high tide level (represented by the Mean Higher High Water (MHHW) tide).

Table 3-1: Sea Level Rise Inundation Scenarios*

Mapping Scenario	Reference Water Level	Applicable Range for Mapping Scenario (Reference +/- 3 inches)
Scenario 1	MHHW + 12-inch	MHHW + 9 – 15 inch
Scenario 2	MHHW + 24-inch	MHHW + 21 – 27 inch
Scenario 3	MHHW + 36-inch	MHHW + 33 – 39 inch
Scenario 4	MHHW + 48-inch	MHHW + 45 – 51 inch
Scenario 5	MHHW + 72-inch	MHHW + 69 – 75 inch
Scenario 6	MHHW + 96-inch	MHHW + 93 – 99 inch

* Colors in the table relate to the water levels in Table 3-2

27 http://www.mtc.ca.gov/planning/climate/RisingTides-TechnicalReport.pdf

In accordance with the most up-to-date SLR projections from the National Research Council (NRC, 2012), the following scenarios were evaluated for the present study: 12-inch, 24-inch, 36-inch, and 48-inch above MHHW. In addition to these scenarios, 72-inch and 96-inch above MHHW (scenarios 5 and 6) were also evaluated, but these water levels are outside the range of current scientific predictions for SLR and, therefore, do not correspond with permanent inundation scenarios that are likely to occur before 2100 (NRC, 2012). These scenarios are included to evaluate important extreme flooding scenarios that could happen during storm surge events with lesser amounts of SLR. In general, though, the scenarios can occur due to SLR, storm surge, or a combination of the two. The six scenarios are listed in Table 3-1.

It is important to understand that the reference water levels listed for each scenario can occur due to a variety of hydrodynamic conditions by combining different amounts of SLR with either a daily[28] or extreme high tide. A +/- 3 inch tolerance was added to each reference water level to increase the applicable range of the mapped scenarios. For example, Scenario 3 (MHHW + 36-inch) is assumed to be representative of all extreme tide/SLR combinations that produce a water level in the range of MHHW + 33 inches to MHHW + 39 inches. By combining different amounts of SLR and extreme tide levels, a matrix of water level scenarios was developed to identify the various combinations represented by each inundation map for the focus areas.

As an example, the matrix of SLR and tide scenarios for the Hayward Focus Area is presented in Table 3-2. The values in Table 3.2 are in shown in inches above the existing conditions MHHW tidal level. The colors shown in Table 3-2 match the colors shown in Table 3-1, and indicate the different combinations of SLR and extreme tide scenarios. The first row of the Table 3.2 shows values for existing conditions. For example, to read Table 3-2, the MHHW + 36-inch scenario (Scenario 3), would also represent a 1-yr extreme tide event with 24 inches of SLR, a 2-yr extreme tide event with 18 inches of SLR, a 5-yr extreme tide event with 12 inches of SLR, etc. Equivalent water levels for the MHHW + 12-inch, MHHW + 24-inch, MHHW + 36-inch, MHHW + 48-inch, MHHW + 72-inch, and MHHW + 96-inch scenarios can be determined similarly by tracking the color coding through Table 3-2. Terms such as “X-inch scenario” and “MHHW + X-inch” are used throughout this section to refer to specific inundation scenarios (e.g., “48-inch scenario” or “MHHW + 48-inch” instead of “48 inches of SLR”) since the scenario can be associated with multiple combinations of SLR and extreme tide events. The matrices of SLR and tide scenarios can also be used to plan for a particular level of risk. For example, to examine infrastructure exposure to a 100-yr extreme tide event with an estimated 6 inches of SLR, the MHHW + 48-inch scenario could be examined. Using this approach, it is possible to assess flood risk to assets at various time scales and frequency of flooding.

Inundation maps were created for each of the focus areas using the six scenarios in Table 3-1, and the methodology developed by the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (Marcy et al. 2011). The inundation maps for the three focus areas were developed by AECOM as a part of the Alameda County Sea Level Rise Shoreline Vulnerability Assessment for BCDC and ACFCWCD and are shown in Appendix B. The maps show inundation areas and depths as well as overtopping potential lines. “Overtopping potential” refers to the condition where the water surface elevation associated with a particular reference water level exceeds the elevation of the shoreline asset. The depth of overtopping potential at each shoreline segment is calculated by taking an average of several depths over the length of the segment.

[28] Mean Higher High Water (MHHW) is used as a surrogate for the average daily high tide. MHHW is the average of the higher high water level of each tidal day observed over the National Tidal Datum Epoch. It should be noted that the actual higher high tide that occurs on any given day will be higher or lower than MHHW. MHHW is approximately 7.0 ft. NAVD88 within this focus area.

Table 3-2: Matrix of Water Levels Associated with Sea Level Rise and Extreme Tide Scenarios for the Hayward Focus Area

	Daily Tide	Extreme Tide (Storm Surge)						
Sea Level Rise Scenario	Water Level above MHHW	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Existing Conditions	0	15	20	24	27	32	36	41
MHHW + 6-inch	6	21	26	30	33	38	42	47
MHHW + 12-inch	12	27	32	36	39	44	48	53
MHHW + 18-inch	18	33	38	42	45	50	54	59
MHHW + 24-inch	24	39	44	48	51	56	60	65
MHHW + 30-inch	30	45	50	54	57	62	66	71
MHHW + 36-inch	36	51	56	60	63	68	72	77
MHHW + 42-inch	42	57	62	66	69	74	78	83
MHHW + 48-inch	48	63	68	72	75	80	84	89
MHHW + 54-inch	54	69	74	78	81	86	90	95
MHHW + 60-inch	60	75	80	84	87	92	96	101

Note: All values in inches above existing conditions MHHW at the Hayward Focus Area. The extreme tide levels above MHHW were derived from the FEMA MIKE 21 model output. Color coding indicates which combinations of sea level rise and extreme tides are represented by the mapping scenarios shown in Table 3-1. Cells with no color coding do not directly correspond to any of the mapping scenarios shown in Table 3-1.

The maps should be used as a planning-level tool only, as the methodology used to develop them have some limitations. Specifically, the methodology 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. Figure 3-1 shows examples of inundation maps for the Bay Bridge, Coliseum, and Hayward Focus Areas, respectively under the MHHW + 36-inch scenario.

3.2 EXPOSURE TO STORM SURGE AND RIVERINE FLOODING IN THE COLISEUM FOCUS AREA

Within the Coliseum Focus Area, several important assets have been identified as vulnerable to riverine flooding in addition to inundation by sea level rise and coastal storm surge. These assets are located in the vicinity of Damon Slough and the surrounding tributaries (Arroyo Viejo Creek and Lion Creek), and as a result an analysis of the combined impact of riverine flooding and coastal storm surge scenarios in this immediate area was conducted. Note that this analysis was not carried out for the Bay Bridge or Hayward Focus Areas. The analysis leveraged an existing steady-state Hydrologic Engineering Center – River Analysis System (HEC-RAS) hydraulic and hydrologic model of Damon Slough, Arroyo Viejo Creek, and Lion Creek from the Alameda County Flood Control and Water Conservation District (ACFCWCD). The HEC-RAS model was used to evaluate various combinations of downstream Bay water levels, sea level rise, and peak flow events in the slough and creek channels to help understand the key thresholds that can result in overbank flow and inundation within the Oakland Coliseum Focus Area. Peak flow events refer to high water levels in the creeks and slough with specific return periods (e.g., 1-, 5-, 10-, 25-, 50-, and 100-year).It should be noted that the HEC-RAS mode was based on 2005 conditions, and model was

Figure 3-1: Examples of Inundation Maps for Focus Areas

Figure 3-1a: Bay Bridge Touchdown Focus Area Inundation Map, MHHW + 36-inch Scenario

Figure 3-1b: Coliseum Focus Area Inundation Map, MHHW + 36-inch Scenario

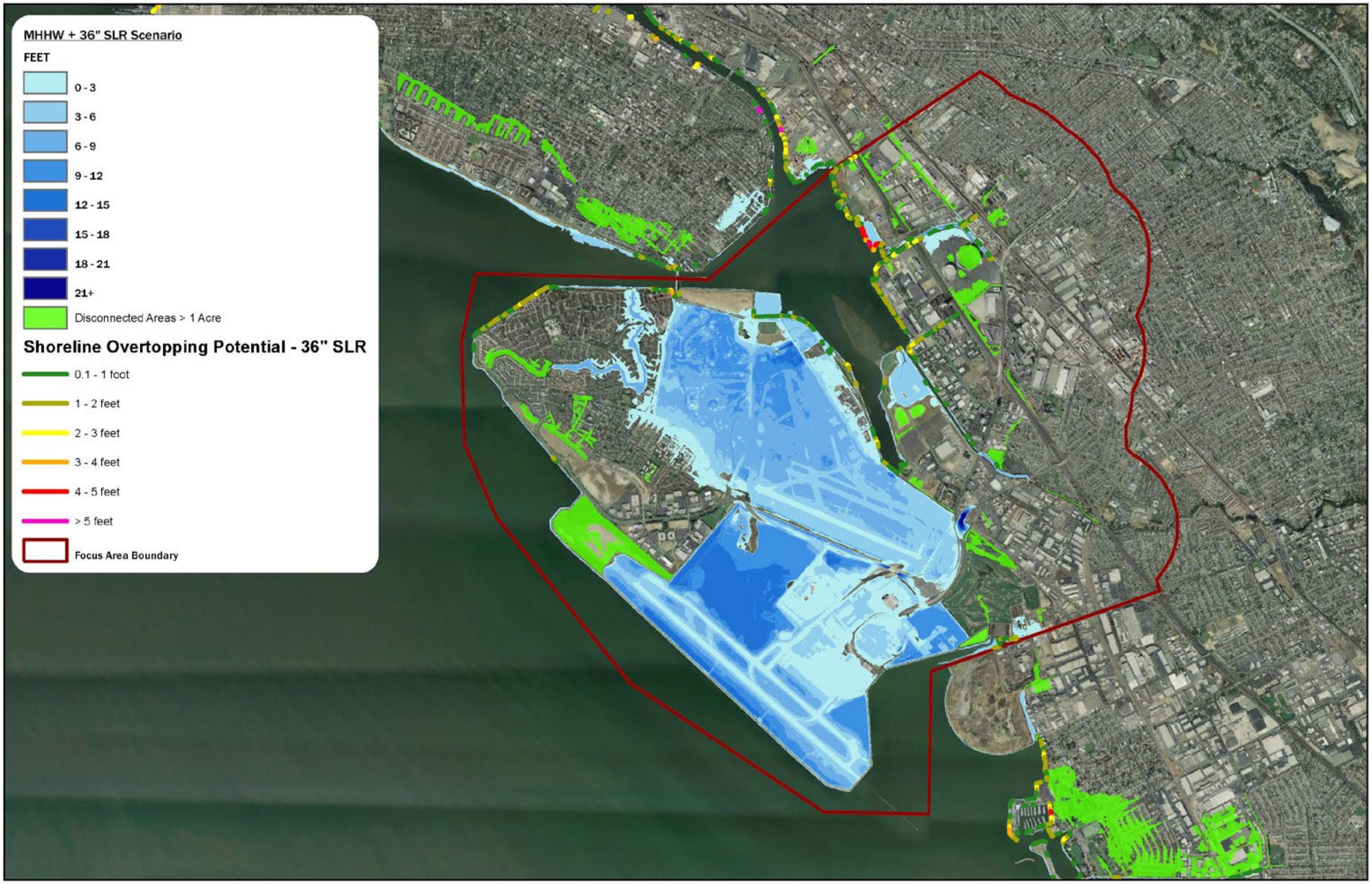
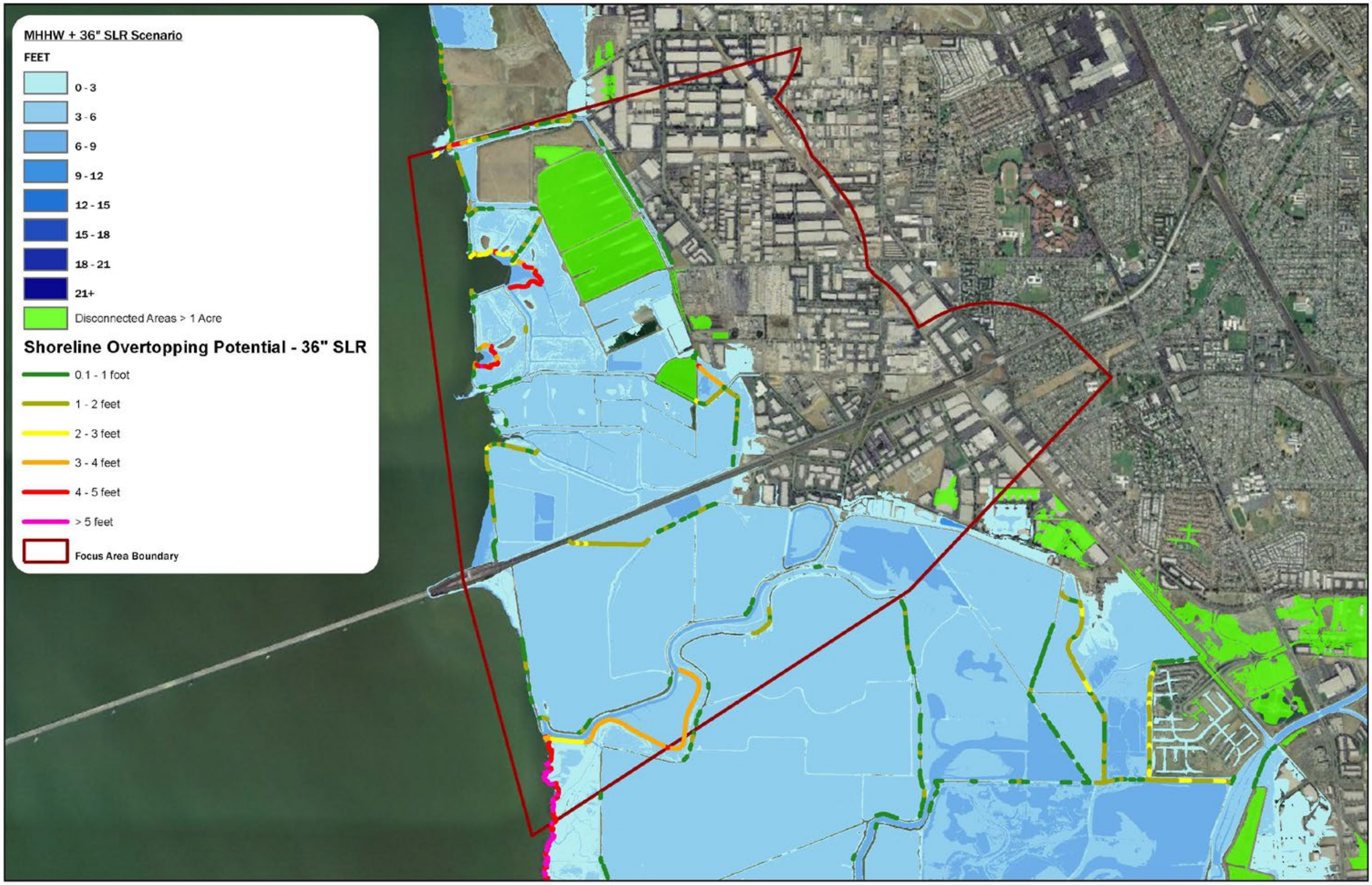


Figure 3-1c: Hayward Focus Area Inundation Map, MHHW + 36-inch Scenario



not updated to account for channel modifications or changes in land use that may have occurred after 2005. The revised channel configurations in Lion Creek were not captured in the model as they were implemented after the calibration of the HEC-RAS model.) Further details on the HEC-RAS model, and the boundary conditions applied within the model, can be found in Appendix B. The modeled scenarios are described below.

3.2.1 STORM SURGE AND RIVERINE FLOODING SCENARIOS

In the discussion that follows, flooding occurs from two distinct processes. The first is riverine flooding – extreme rainfall runoff driven peak flow events in the stream network during periods of average high tide conditions in the Bay. The second is combined riverine and storm surge flooding – smaller peak flows in the stream network that coincides with periods of episodic, short duration, extreme tide events of greater magnitude than normal tide levels. Inland areas may be temporarily flooded during a riverine flood or combined riverine and storm surge event while maintaining at least a portion of their functionality once the floodwaters recede. However, sensitive assets may suffer irreversible damage if exposed to any amount of water, even temporarily. Assets would only be exposed to freshwater from riverine flooding, but could be exposed to saline water during flooding from combined riverine and storm surge events.

The HEC-RAS model (described in Appendix B) was used to evaluate various combinations of downstream Bay water levels (i.e., MHHW, 10-year storm surge, and 100-year storm surge), sea level rise (i.e., 12 inches and 24 inches), and peak flow events in the slough and creek channels (i.e., 10-year flow and 100-year flow). Although numerous potential combinations of Bay water levels, sea level rise, and peak flow events could have been used to evaluate the system, the selected combination of events were designed to help understand the key thresholds that can result in overbank flow and inundation within the Oakland Coliseum Focus Area.

Average daily tide conditions were represented by applying the MHHW level at the downstream boundary. The 10-year storm surge elevation is comparable to a typical El Niño winter condition, and the 100-year storm surge elevation is the coastal flood hazard level used by FEMA for developing Flood Insurance Rate Maps for coastal communities. In the absence of riverine flooding, the critical threshold for inundation occurs with 36 inches of sea level rise. However, when riverine flooding is also considered, the threshold is likely lower; therefore two lower sea level rise scenarios were evaluated in combination with the riverine flooding: 12 and 24 inches.

The 10- and 100-year peak flow rates for the Damon Slough, Arroyo Viejo, and Lion Creek reaches were paired with the various downstream tidal boundary conditions. The 10-year peak flow rate can be associated with a precipitation event that occurs during an El Niño winter, and similarly with the coastal storm surge elevations, the 100-year peak flow rate is typically used by FEMA for calculating base flood elevations as shown on the FIRMs for communities adjacent to rivers and creeks.

A summary table of the simulations evaluated using the HEC-RAS model is presented in Table 3-3. The 100-year coastal storm surge elevation was not evaluated in combination with the 100-year riverine peak flow event. This combination would represent an event with a recurrence interval much greater than a 100-year event. The goal of this analysis was to determine the thresholds when inundation begins, and not necessarily to evaluate extreme inundation scenarios.

3.2.2 SLR, STORM SURGE AND RIVERINE FLOODING MAP DEVELOPMENT

The inundation mapping for this focus area relied on two primary data sources:

- 2-meter digital elevation model (DEM) developed from the 2010 Light Detection and Ranging (LiDAR) data collected by the USGS and NOAA as part of the California Coastal Mapping Program (CCMP)
- HEC-RAS model output water surface elevations at each channel cross section

Table 3-3: Selected Analysis Scenarios

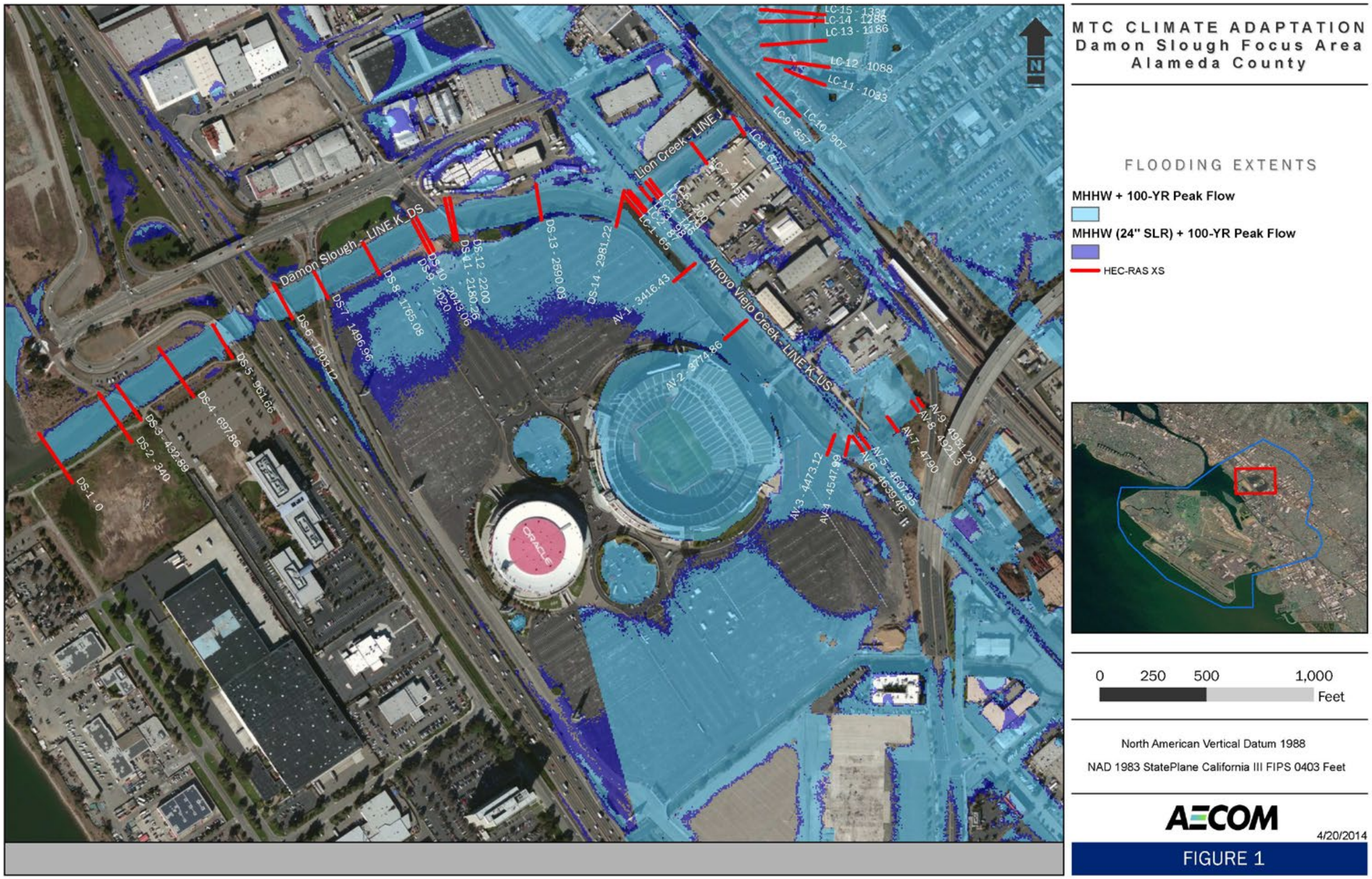
TIDE CONDITION	PEAK FLOW	DESCRIPTION
MHHW	**10-year**	10-year peak flow rate during higher high tide conditions.
+ 12-inch SLR	10-year	10-year peak flow rate during higher high tide conditions with 12-inch SLR.
+ 24-inch SLR	10-year	10-year peak flow rate during higher high tide conditions with 24-inch SLR.
MHHW	**100-year**	100-year peak flow rate during higher high tide conditions. 100-year peak discharge typical for FEMA studies.
+ 12-inch SLR	100-year	100-year peak flow rate during higher high tide conditions with 12-inch SLR.
+ 24-inch SLR	100-year	100-year peak flow rate during higher high tide conditions with 24-inch SLR.
10-year	**10-year**	10-year peak flow rate during 10-year storm surge levels. Similar to typical event experienced during El Niño winter.
+ 12-inch SLR	10-year	10-year peak flow rate during 10-year storm surge conditions with 12-inch SLR.
+ 24-inch SLR	10-year	10-year peak flow rate during 10-year storm surge conditions with 24-inch SLR.
10-year	**100-year**	100-year peak flow rate during 10-year storm surge conditions.
+ 12-inch SLR	100-year	100-year peak flow rate during 10-year storm surge conditions with 12-inch SLR.
+ 24-inch SLR	100-year	100-year peak flow rate during 10-year storm surge conditions with 24-inch SLR.
100-year	**10-year**	10-yr peak flow rate during 100-year storm surge conditions. 100-year storm surge typical for FEMA studies.
+ 12-inch SLR	10-year	10-year peak flow rate during 100-year storm surge conditions with 12-inch SLR.
+ 24-inch SLR	10-year	10-year peak flow rate during 100-year storm surge conditions with 24-inch SLR.

After spatially adjusting the existing HEC-RAS model to the correct horizontal datum, the flood extent mapping for the Oakland Coliseum Focus Area was completed using AECOM's proprietary Hydraulic Analyst toolbox for ESRI's ArcMap software (see Appendix B for more details). Although fifteen combinations of Bay water levels, sea level rise, and riverine peak flows were analyzed, as shown in Table 3-3 only eight scenarios were modeled for illustrative purposes, as presented in Table 3-4. There were limited differences observed on the maps between 12- and 24-inches of sea level rise; therefore only the existing conditions and 24 inches of sea level rise scenarios were mapped to compare the differences in flooding extent. An example of Mapping Scenario 1 corresponding to the modelled scenario in Table 3-4 is shown in Figure 3-2. It is important to note that Tables 3-3 and 3-4 show scenarios in which sea level rise, storm surge, and peak flow events combine to create an elevated water level. These water levels are subsequently used as mapping scenarios. Maps showing Mapping Scenario 2, 3 and 4 can be found in Appendix B. The maps can be used to enhance the overall understanding of the flooding vulnerabilities at the core transportation assets within the Oakland Coliseum Focus Area.

Table 3-4: Mapped HEC-RAS Simulations

Mapping Scenario	Modeled Scenario
Mapping Scenario 1	MHHW + 100-year Peak Flow
	MHHW + 24-inch SLR + 100-year Peak Flow
Mapping Scenario 2	10-year Extreme Tide + 10-year Peak Flow
	10-year Extreme Tide + 24-inch SLR + 10-year Peak Flow
Mapping Scenario 3	10-year Extreme Tide + 100-year Peak Flow
	10-year Extreme Tide + 24-inch SLR + 100-year Peak Flow
Mapping Scenario 4	100-year Extreme Tide + 10-year Peak Flow
	100-year Extreme Tide + 24-inch SLR + 10-year Peak Flow

Figure 3-2: Mapping Scenario 1

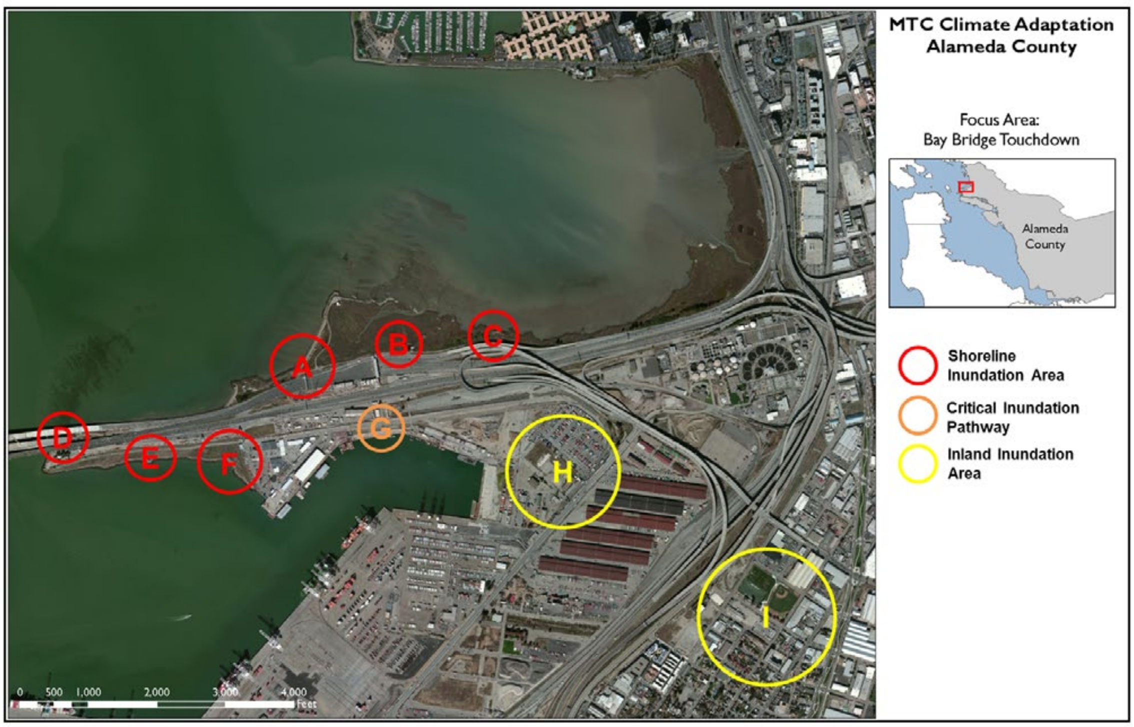


3.3 REFINED EXPOSURE ANALYSIS RESULTS FOR BAY BRIDGE TOUCHDOWN FOCUS AREA

Nine key areas of vulnerability within the Bay Bridge Touchdown Focus Area were identified based on the results of the inundation mapping under the MHHW +36-inch scenario for which detailed analysis was undertaken. Assets in the southern portion of the Bay Bridge Touchdown Focus Area were not found to be inundated under this scenario. The inundation mapping analysis shows that the southern portion of the Bay Bridge Touchdown Focus Area will only be start to be inundated under the MHHW +48-inch scenario and higher.

Scenarios which lead to inundation and proximity to important assets were the fundamental criteria used to select these areas, which are identified in Figure 3-3 and labeled letters “A” through “I”. These nine areas are grouped into three categories -- *shoreline inundation areas*, *critical inundation pathways*, and *inland inundation areas*. In Figure 3-3, shoreline inundation areas (A-F) are labeled in red, critical inundation pathways (G) in orange, and inland inundation areas (H-I) in yellow.

Figure 3-3: Bay Bridge Touchdown Focus Area Site Location Map and Inundation Areas



Note: Circles are used to indicate approximate locations and extents of inundation. Circle sizes do not correspond to intensity, timing, or risk of inundation.

Shoreline inundation areas are immediately adjacent to the shoreline and are both the most vulnerable to flooding and the most likely to experience permanent inundation as a result of sea level rise. These areas are where the shoreline will first be overtopped and from which floodwaters will propagate to areas immediately inland[29]. Six shoreline inundation areas were identified for the Bay Bridge Touchdown Focus Area and are discussed in Section 3.3.1.

[29] The SLR scenario when the site is first overtopping has been approximated based on the mapped sea level rise inundation scenarios (e.g., 12”, 24”, 36”, and 48”). The actual SLR scenario which results in overtopping may be less than this amount (i.e., if the SLR scenario of first overtopping is 36 inches, overtopping is first observed in this mapped scenario, but overtopping may occur as early as 25 inches). Refined shoreline tools have been developed for this area that can estimate the overtopping threshold within 6 inch increments, and these tools can be used for future updates to this assessment.

Critical inundation pathways connect shoreline inundation areas to the inland inundation areas, providing the necessary hydraulic connectivity to convey floodwaters to inland areas. One critical inundation pathway was identified within the Bay Bridge Touchdown Focus Area and is discussed in Section 3.3.2.

Inland inundation areas are not directly on the shoreline and require a hydraulic pathway to convey floodwaters from the Bay to the inland area. These areas are the least likely to experience the full extent of temporary flooding depicted in the inundation maps due to the typical duration of a coastal storm surge event and the volume of water that would be required to fill these expansive low-lying areas during an episodic event. To determine the exact extent of inland flooding or permanent inundation, more sophisticated modeling is required; however, the exposure of these areas to potential inundation and flooding is well represented by the inundation maps for the purposes of this study. Two inland inundation areas were identified within the Bay Bridge Touchdown Focus Area and are discussed in Section 3.3.4.

3.3.1 SHORELINE INUNDATION AREAS

Six shoreline inundation areas were identified and are summarized below:

- Area A (Figure 3-4)
    - Limited inundation occurs near the toll plaza as early as MHHW + 12-inch scenario
    - Inundation of the westbound highway lanes first occurs at the MHHW +36-inch scenario with inundation depths of 0-3 feet
- Area B (Figure 3-4)
    - Limited inundation occurs near the toll plaza as early as MHHW +24-inch scenario
    - Partial inundation of the westbound highway lanes first occurs at the MHHW +36-inch scenario
- Area C (Figure 3-4)
    - Partial inundation of the westbound highway lanes first occurs at the MHHW +36-inch scenario
    - Inundation underneath elevated highway segments
- Area D (Figure 3-5)
    - Access road and buildings are partially inundated first at the MHHW +36-inch scenario
    - Inundation underneath elevated highway segments
- Area E (Figure 3-5)
    - Burma Road is partially inundated at MHHW +36-inch scenario with depths of 0-3 feet
- Area F (Figure 3-5)
    - Burma Road and some nearby buildings are partially inundated first at the 36-inch scenario with inundation depths of 0-3ft

Figure 3-4: Shoreline Inundation Areas A, B, and C - MHHW + 36-inch Scenario

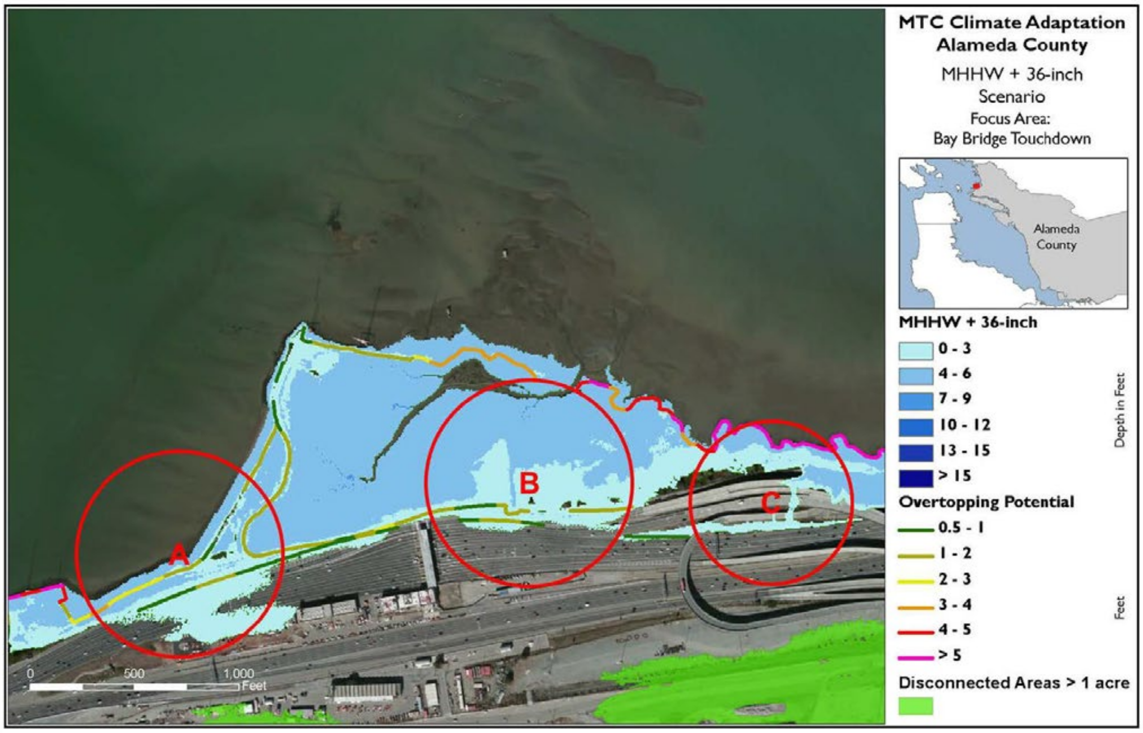
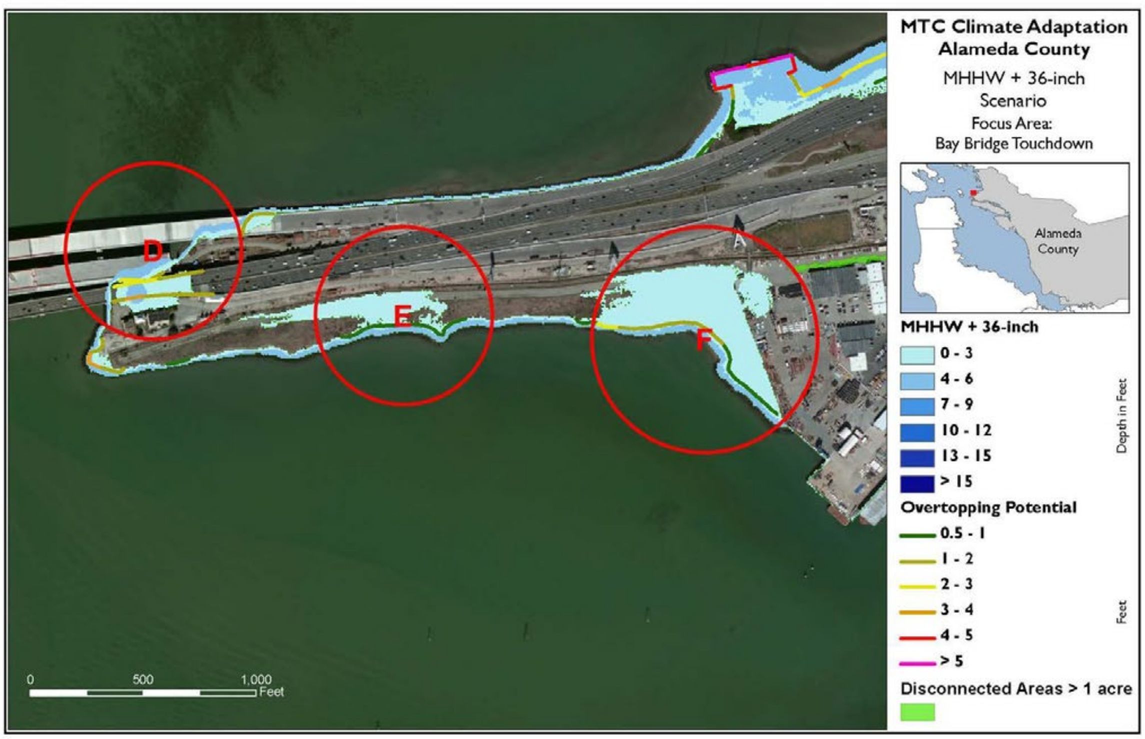


Figure 3-5: Shoreline Inundation Areas D, E, and F - MHHW + 36-inch Scenario



3.3.2 CRITICAL INUNDATION PATHWAYS

One critical inundation pathway was identified at the Bay Bridge Touchdown Focus Area (Area G in Figure 3-6). This low-lying hydraulic pathway allows floodwaters to penetrate landward from the shoreline to the inland inundation Areas H and I (Figure 3-6). Given the relatively large extent of inland inundation observed, AECOM sought to verify the mechanism of flooding and accuracy of the digital elevation model (DEM)[30] upon which the inundation maps were based to confirm the likelihood of flooding depicted. The DEM was compared to the original topographic Light Detection and Ranging (LiDAR) data points for this area to confirm that the modeled terrain surface of the DEM accurately represented the raw LiDAR data. Additionally, the orthoimagery from the 2010 LiDAR data collection and aerial photography from Google Earth (2014) were examined to confirm the location of the pathway and its surrounding features. Based on these examinations, the pathway appears to be formed by an engineered stormwater drainage area along Burma Road, which most likely drains to the Bay. Although intended for mitigating flooding due to precipitation and runoff, this stormwater drainage system may allow coastal floodwaters to propagate inland. It should be noted that recent development in the area south of the Touchdown, as well as future planned projects (e.g., Gateway Park) which include grade changes, may alter the inundation pathways in the future.

Figure 3-6: Critical Inundation Pathway (Area G) and Inland Inundation Areas (H-I) - MHHW + 48-inch Scenario

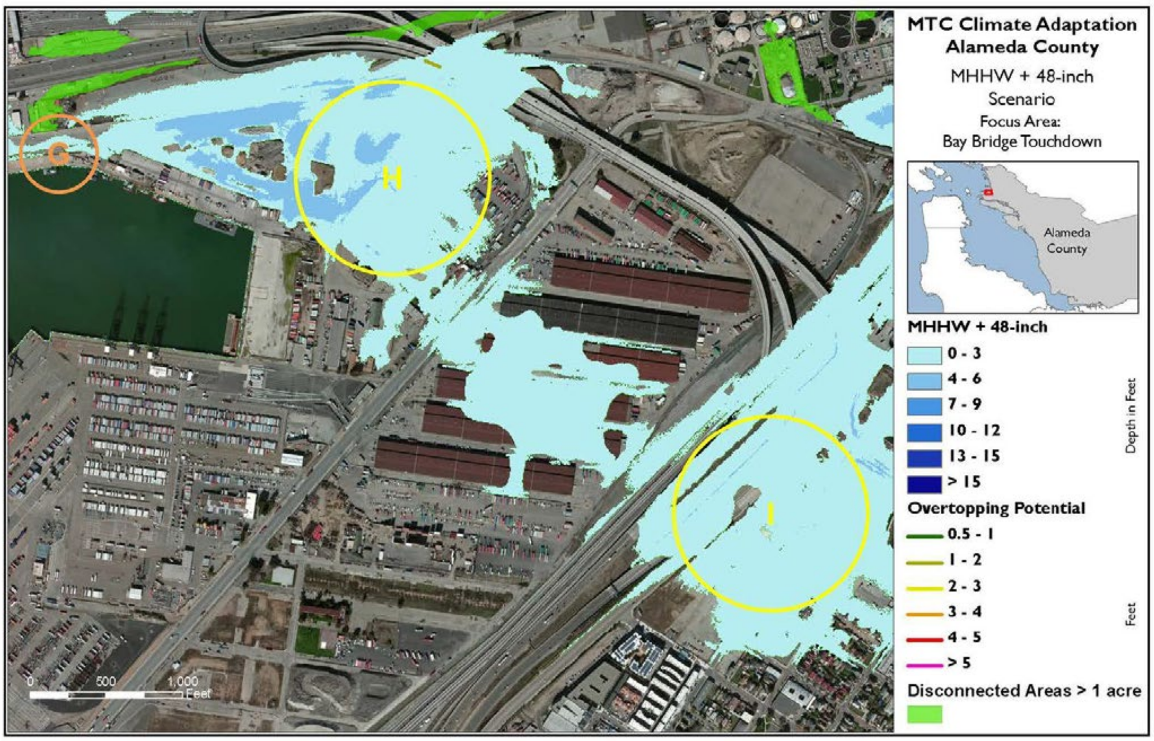


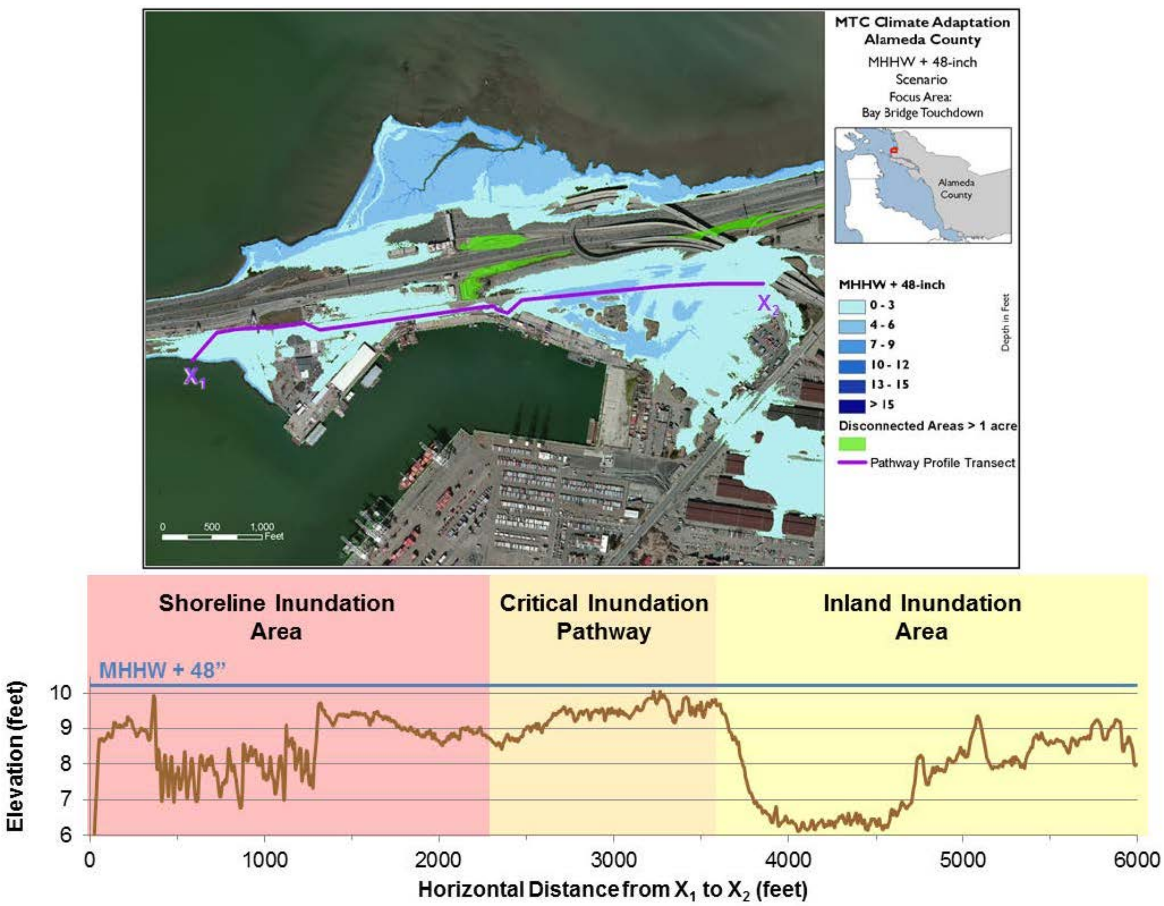
Figure 3-7 shows the elevation profile along the critical inundation pathway starting at the shoreline near Areas E and F and extending inland to Area H. The MHHW + 48-inch water level is shown for reference relative to the topography. As can be seen in Figure 3-7, the MHHW + 48-inch water level overtops both the shoreline protection infrastructure and the high point of the critical inundation pathway at an elevation

30 A 2-meter digital elevation model (DEM) was developed from the 2010 LiDAR data collected by the United States Geological Survey (USGS) and National Oceanic Atmospheric Administration (NOAA) as part of the California Coastal Mapping Program (CCMP)

of approximately 10 feet NAVD88. Once both of these features are overtopped, there is a continuous hydraulic connection from the shoreline to the inland inundation areas, which conveys floodwaters landward. Key observations for this critical inundation pathway are summarized below:

- Area G
  - Inundation occurs at critical water level of approximately 10 feet NAVD88
  - Narrow drainage pathway along Burma Road at Port of Oakland Berth 8 connects the flooding from Areas E and F (Figure 3-5) to Areas H and I
  - Inundation first occurs at the 48-inch scenario with inundation depths of 0-3 feet
- Area H
  - Extensive inundation first occurs at the 48-inch scenario with depths of 0-6 feet
  - Mostly industrial land uses
- Area I
  - Extensive inundation first occurs at the 48-inch scenario with depths of 0-6 feet
  - I-880, residential and commercial land uses

Figure 3-7: Plan and Profile View of Critical Inundation Pathway Connecting the Shoreline with Inland Inundation Areas

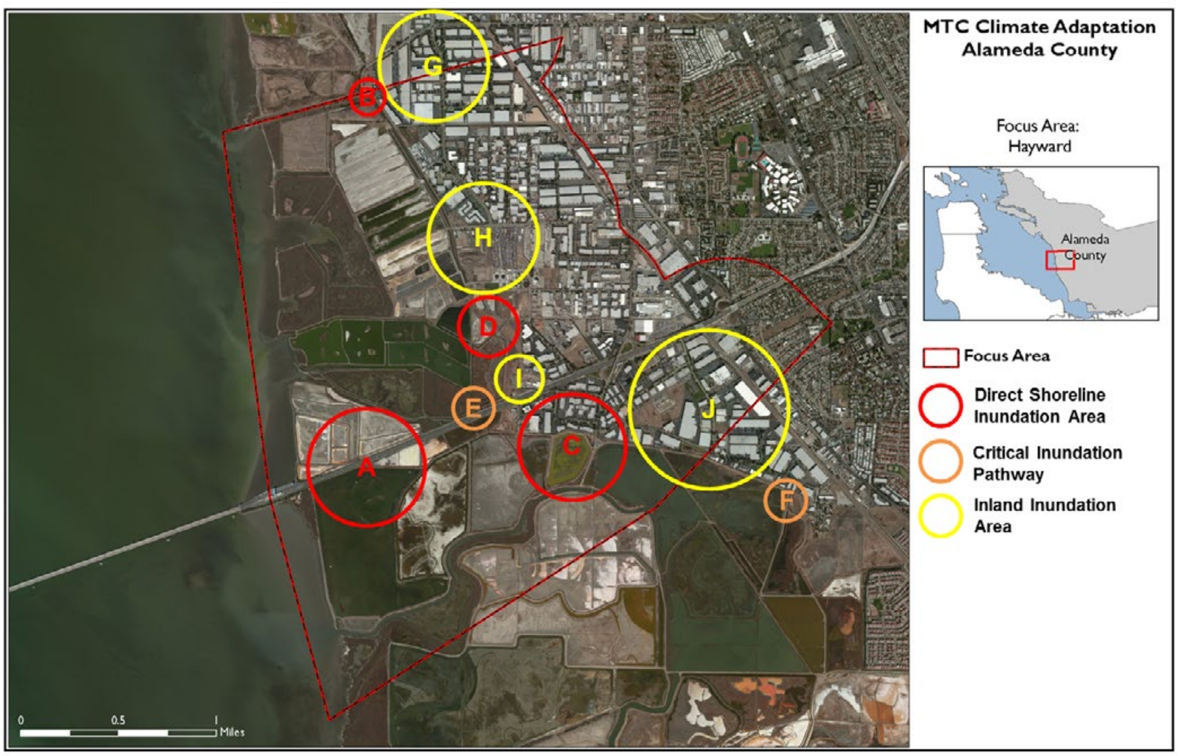


Note: Profile outlined in purple in the plan view. Profile stationing reads from west (X1) to east (X2).

3.4 REFINED EXPOSURE ANALYSIS RESULTS FOR HAYWARD FOCUS AREA

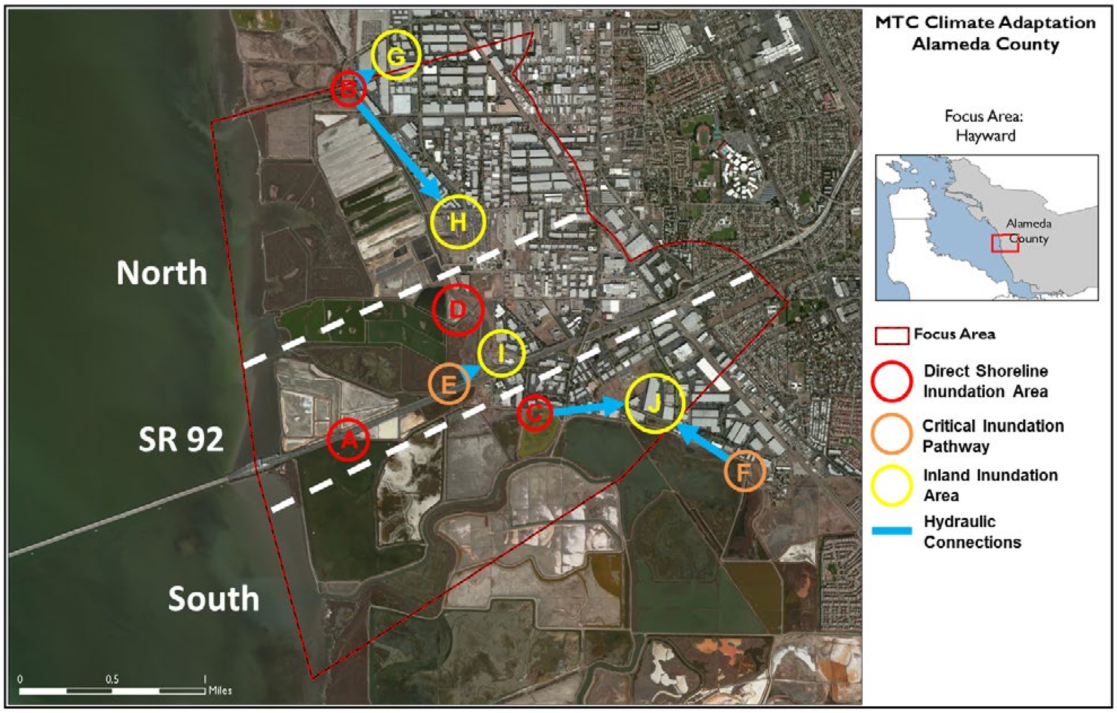
Ten key areas of vulnerability were identified within the Hayward Focus Area based on a detailed review of the inundation mapping. Timing of inundation and proximity to important assets were the fundamental criteria used to select these areas, which are identified in Figure 3-8 and Figure 3-9 and labeled letters "A" through "J." These areas are grouped into three categories—*shoreline inundation areas*, *critical inundation pathways*, and *inland inundation areas* as defined in Section 3.3. In both figures, shoreline inundation hazard areas are labeled in red (A-D), critical inundation pathways in orange (E-F), and inland inundation areas in yellow (G-J). Figure 3-9 also shows a general overview of the sources of flooding and the pathways that allow floodwaters to progress inland. To facilitate understanding, the Hayward Focus Area has been subdivided into three regions based on the flooding patterns within the focus area that occur with less than 36 inches of sea level rise (Figure 3-9): the area North of SR 92 (North); the area at and adjacent to SR 92 (SR 92); and the area South of SR 92 (South). Results for areas north of SR 92 are presented in Section 3.4.2; results for areas immediately adjacent to SR 92 are presented in Section 3.4.2.1; and results for areas south of SR 92 are presented in Section 3.4.3.2.

Figure 3-8: Hayward Focus Area Site Location Map and Inundation Areas



Note: Circles are used to indicate approximate locations and extents of inundation. Circle sizes do not correspond to intensity, timing, or risk of inundation.

Figure 3-9: Delineation of Inundation Regions and Connections between Inundation Areas

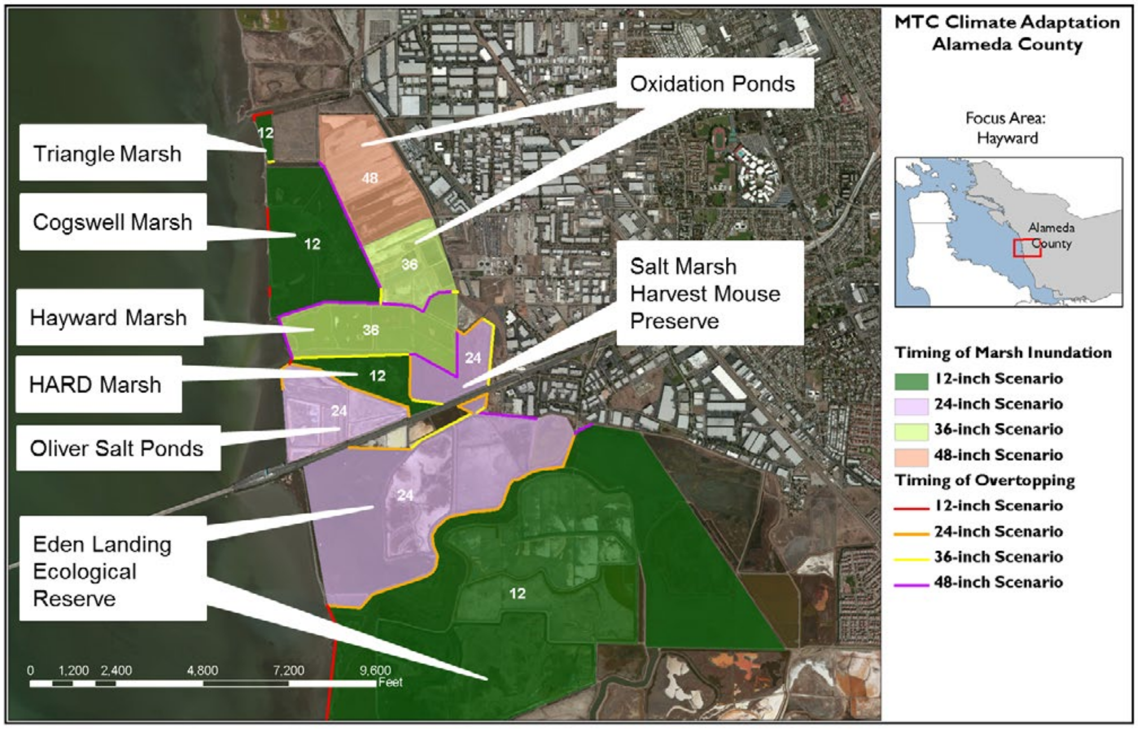


3.4.1 MANAGED MARSHES AND PONDS

There are eight distinct marsh areas or ponds within the Hayward Focus Area, and these areas are typically separated by a network of internal and bayfront berms (Figure 3-10). The majority of this system is part of the Hayward Regional Shoreline, with the exception of Eden Landing Ecological Reserve, which is part of the Eden Landing system owned by the California Department of Fish and Wildlife. Figure 3-10 shows which scenarios will result in inundation throughout the system and the critical segments that will be overtopped, thereby inundating the adjacent area(s). Triangle Marsh, Cogswell Marsh, HARD Marsh and Eden Landing Ecological Reserve are directly connected to the Bay by natural and/or engineered inlets and are actively flooded under existing conditions. The eight inundation areas are summarized below (see Figure 3-10):

- Triangle Marsh
    - Inundation first occurs at MHHW +12-inch scenario with inundation depths of 0-6 feet
    - Fully tidal under existing conditions
- Cogswell Marsh
    - Inundation first occurs at MHHW +12-inch scenario with inundation depths of 0-6 feet
    - Fully tidal under existing conditions
- Hayward Marsh
    - Inundation first occurs at MHHW +36-inch scenario with inundation depths of 0-3 feet
- HARD Marsh
    - Inundation first occurs at MHHW +12-inch scenario with inundation depths of 0-6 feet
    - Fully tidal under existing conditions

Figure 3-10: Timing of Bayfront Inundation and Locations of Overtopping at Non-Engineered Berms



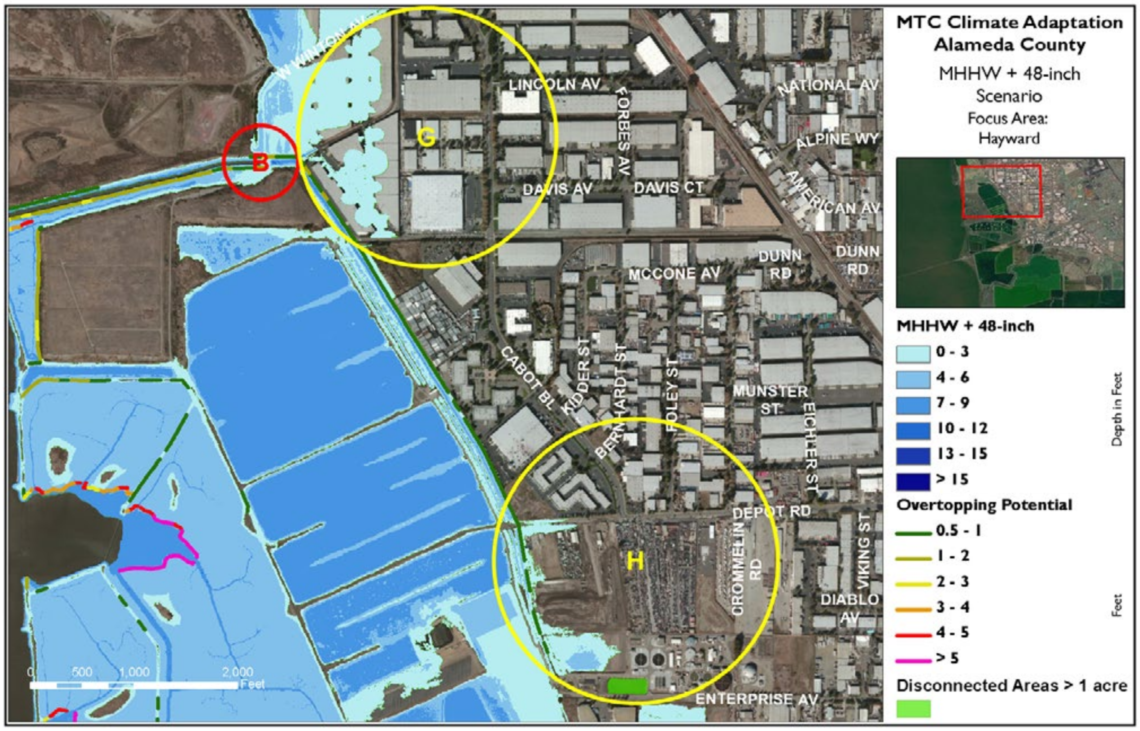
Note: Numbers denote the first SLR scenario that results in inundation (in inches above MHHW).

- Oliver Salt Ponds
  - Inundation first occurs at the MHHW +24-inch scenario with inundation depths of 0-6 feet
- Oxidation Ponds
  - Inundation occurs south at MHHW +36-inch scenario with inundation depths of 0-9 feet
  - Entire area is inundated at MHHW +48-inch scenario with inundation depths of 0-9 feet
- Salt Marsh Harvest Mouse Preserve
  - Inundation first occurs at MHHW +24-inch scenario with inundation depths of 0-6 feet
- Eden Landing Ecological Reserve
  - Partial inundation occurs at MHHW +12-inch scenario with inundation depths of 0-3 feet
  - Entire area is inundated at MHHW +24-inch scenario with inundation depths of 0-9 feet

3.4.2 NORTH OF SR 92

North of SR 92, the primary sources of inundation are from natural and engineered flood control channels that are overtopped (Figure 3-11). One shoreline inundation area (Area B) was identified in this region as well as two inland inundation areas (Areas G and H). Shoreline inundation areas are presented in Section 3.4.2.1 and inland inundation areas are presented in Section 3.4.2.2.

Figure 3-11: Inundation Areas North of SR 92 (MHHW + 48-inch Scenario)



3.4.2.1 SHORELINE INUNDATION AREAS

One shoreline inundation area (Area B) was identified in the region north of SR 92 and results in the exposure of inland assets located in Area G, as summarized below:

- Area B (Figure 3-11)
  - Overtopping of the engineered flood control channels east of Triangle Marsh first occurs at the MHHW +36-inch scenario with inundation depths of 0-3 feet
  - W. Winton Avenue is partially inundated from areas to the north and from overtopping of the flood control channel to the south
  - Industrial buildings and parking lots are partially inundated (Area G)

3.4.2.2 INLAND INUNDATION AREAS

Two inland inundation areas (Areas G and H) were identified in the region north of SR 92. Both are inundated as a result of overtopped natural and engineered channels. A summary of the inland inundation areas for this region is included below:

- Area G (Figure 3-11)
  - Mostly industrial and parking areas
  - Inundation first occurs at the MHHW +36-inch scenario with depths of 0-3 feet
  - Source of flooding is overtopped channels at Area B
- Area H (Figure 3-11)
  - Mostly industrial and parking areas
  - Inundation first occurs at the MHHW +48-inch scenario with depths of 0-3 feet

- o Source of flooding is overtopped natural and flood control channels east of the oxidation ponds
- o City of Hayward Water Pollution Control Facility is partially flooded at the MHHW +72-inch scenario with depths of 0-3 feet

3.4.3 SR 92

Adjacent to SR 92, inundation occurs primarily from overtopping of non-engineered berms along Oliver Salt Ponds, HARD Marsh, and Salt Marsh Harvest Mouse Preserve (Figure 3-12 and Figure 3-13). Two shoreline inundation areas (Areas A and D, Section 3.4.3.1) were identified in this region. Additionally, a critical inundation pathway (Area E, Section 3.4.3.2) results in inundation of inland areas (Area I, Section 3.4.4.3).

3.4.3.1 SHORELINE INUNDATION AREAS

Two shoreline inundation areas (Areas A and D) were identified at SR 92. A summary of the shoreline inundation areas is presented below:

- Area A (Figure 3-12)
  - o Partial inundation of Breakwater Avenue first occurs at the MHHW +36-inch scenario with inundation depths of 0-3 feet
  - o Partial inundation of the outermost highway lanes south of the Oliver Salt Ponds first occurs at the MHHW +48-inch scenario with inundation depths of 0-3 feet
- Area D (Figure 3-13)
  - o Overtopping of the non-engineered berm in the area north of the Salt Marsh Harvest Mouse Preserve first occurs at the MHHW +24-inch scenario with inundation depths of 0-3 feet
  - o Antenna towers near Enterprise Avenue are partially inundated

Figure 3-12: Inundation at Area A (MHHW + 48-inch Scenario)

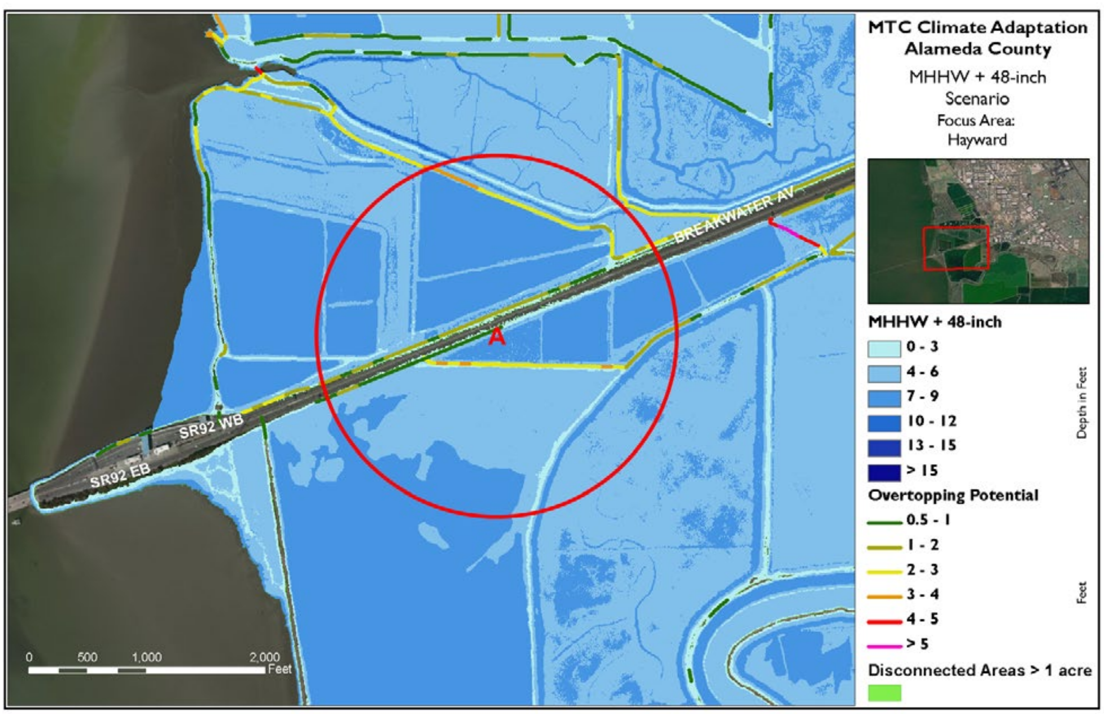
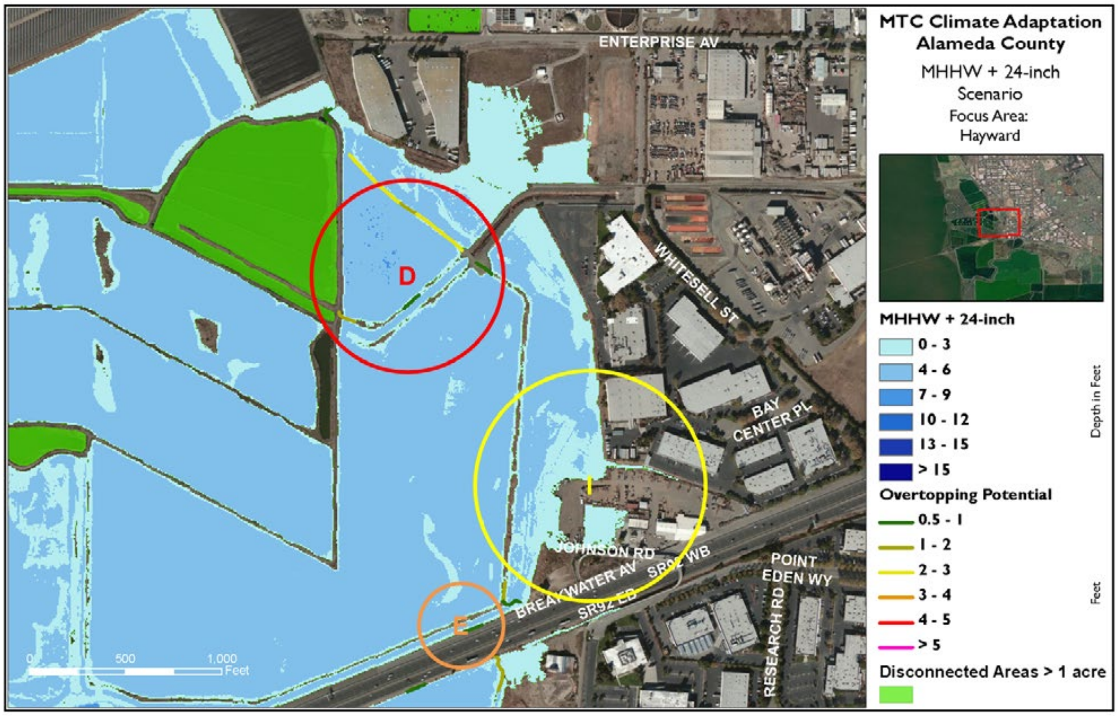


Figure 3-13: Areas of Inundation Adjacent to SR 92 (MHHW + 24-inch Scenario)



3.4.3.2 CRITICAL INUNDATION PATHWAYS

One critical inundation pathway (Area E) was identified at SR 92. It is first overtopped at the 24-inch scenario (Figure 3-13). A single controlling feature was confirmed at the landward terminus of the channel along Breakwater Avenue at the Salt Marsh Harvest Mouse Preserve that results in extensive inland inundation of adjacent areas when overtopped. The high point of the critical inundation pathway occurs at an elevation of approximately 8 feet NAVD88. Figure 3-14 shows a representative transect of the elevation profile along Area E starting in the channel and extending inland over the non-engineered berm. Key observations are summarized below:

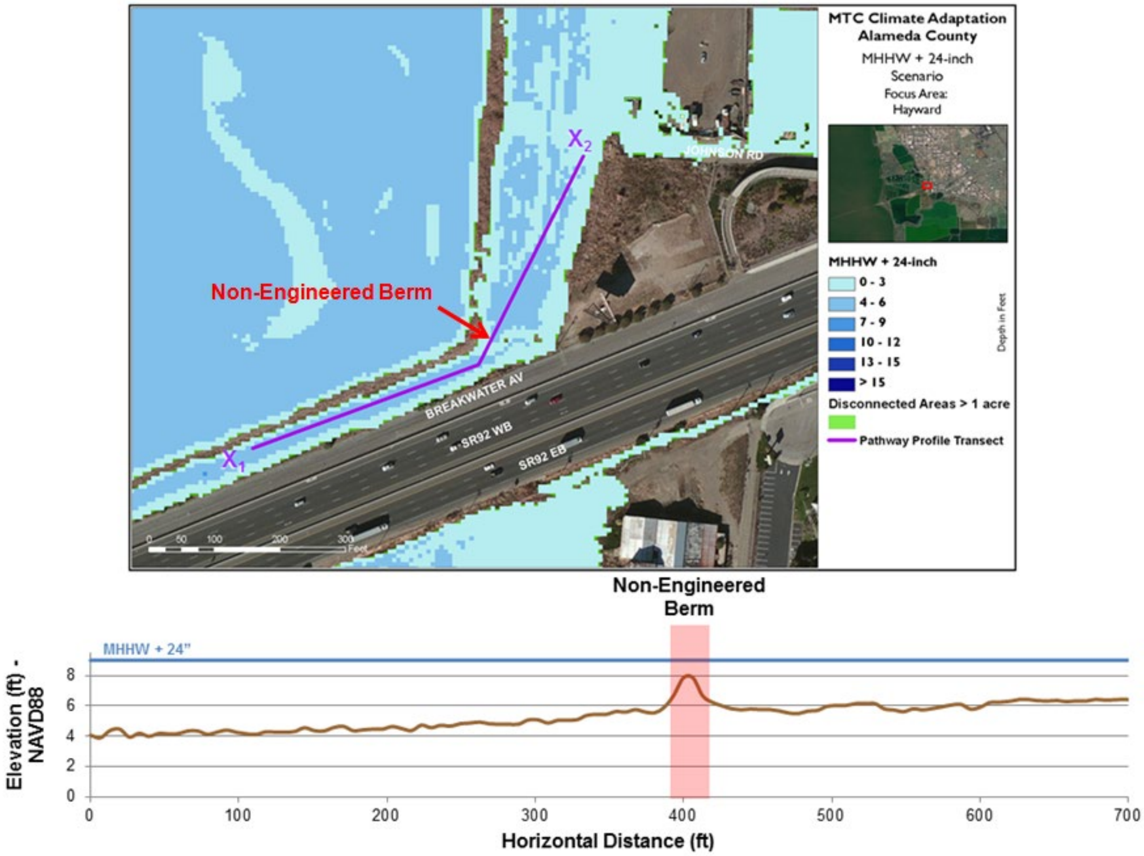
- Area E (Figure 3-13; Figure 3-14)
  - Narrow channel along Breakwater Avenue is inundated, overtopped at the southeast corner of Salt Marsh Harvest Mouse Preserve and connects the flooding from HARD Marsh to inland Area I
  - First occurs at the MHHW +24-inch scenario with inundation depths of 0-3 feet, immediately east of Hayward Shoreline Interpretive Center
  - Critical water level of approximately 8 feet NAVD88

3.4.3.3 INLAND INUNDATION AREAS

One inland inundation area (Area I) was identified at SR 92. More extensive flooding occurs at the MHHW + 36-inch scenario when the non-engineered berm that forms the eastern boundary of Salt Marsh Harvest Mouse Preserve is overtopped almost entirely. Key observations are summarized below:

- Area I (Figure 3-13)
  - Inundation first occurs at the MHHW +24-inch scenario with depths of 0-3 feet. Source of flooding is HARD Marsh via Area E

Figure 3-14: Plan and Profile of Critical Inundation Pathway (Area E) Connecting the Wetland Channel with Inland Inundation Areas



Note: Profile outlined in purple in the plan view. Profile stationing reads from west (X1) to east (X2).

3.4.4 SOUTH OF SR 92

South of SR 92, inundation occurs primarily due to overtopping of non-engineered berms east of the Eden Landing Ecological Reserve. One shoreline inundation area (Area C, Section 3.4.3.2), one critical inundation pathway (Area F, Section 3.4.4.2), and one inland inundation area (Area J, Section 3.4.4.3) were identified in this region.

3.4.4.1 SHORELINE INUNDATION AREAS

One shoreline inundation area (Area C) was identified for the region south of SR 92. Key observations are summarized below:

- Area C (Figure 3-15)
    - Overtopping of the non-engineered berm in the northeast area of Eden Landing Ecological Reserve occurs at the MHHW +48-inch scenario with inundation depths of 0-3 feet
    - Eden Landing Road and Arden Road are partially inundated
    - Industrial buildings and parking lots are partially inundated

3.4.4.2 CRITICAL INUNDATION PATHWAYS

One critical inundation pathway (Area F) was identified south of SR 92, with overtopping first observed in the 24-inch scenario. Given the relatively large extent of inland inundation observed as a result of overtopping at Area F, AECOM verified the pathways of flooding and accuracy of the DEM using the same process described in Section 3.3.2. The extensive inland inundation occurs when a berm located at the landward terminus of a channel near the intersection of Arden Road and Baumberg Avenue (east of Eden Landing Ecological Reserve) is overtopped. Figure 3-17 shows a representative transect of the elevation profile along Areas F starting in the channel and extending inland over the non-engineered berm. Key observations for the critical inundation pathway are summarized below:

- Area F (Figure 3-16 and Figure 3-17)
  - Narrow channel along the inland side of the non-engineered berm fronting Eden Landing Ecological Reserve at Arden Road connects the flooding from southern areas of Eden Landing Ecological Reserve to inland Area J
  - First occurs at the MHHW +24-inch scenario with inundation depths of 0-3 feet
  - Critical water level of approximately 9 feet NAVD88

3.4.4.3 INLAND INUNDATION AREAS

One inland inundation area (Area J) was identified south of SR 92 (Figure 3-15 and Figure 3-16). This extensive area along Arden Road and Trust Way is exposed due to overtopping of non-engineered berms at Area C (48-inch scenario) and overtopping of the critical inundation pathway at Area F (24-inch scenario). Key observations are summarized below:

- Area J (Figure 3-15 and Figure 3-16)
  - Mostly industrial and parking areas
  - Inundation first occurs at the MHHW +24-inch scenario with depths of 0-3 feet
  - Source of flooding is Eden Landing Ecological Reserve via Areas F and C

Figure 3-15: Inundation at Areas C and J (MHHW + 48-inch Scenario)

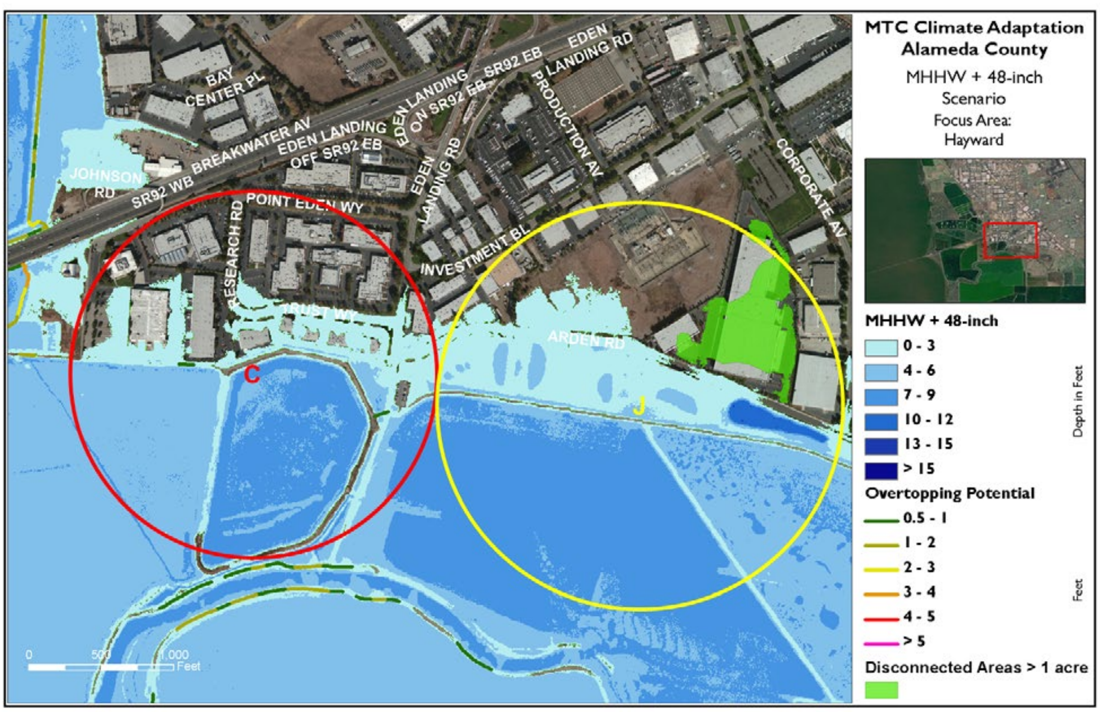


Figure 3-16: Critical Inundation Pathway F & Inland Inundation Area J (MHHW + 24-inch)

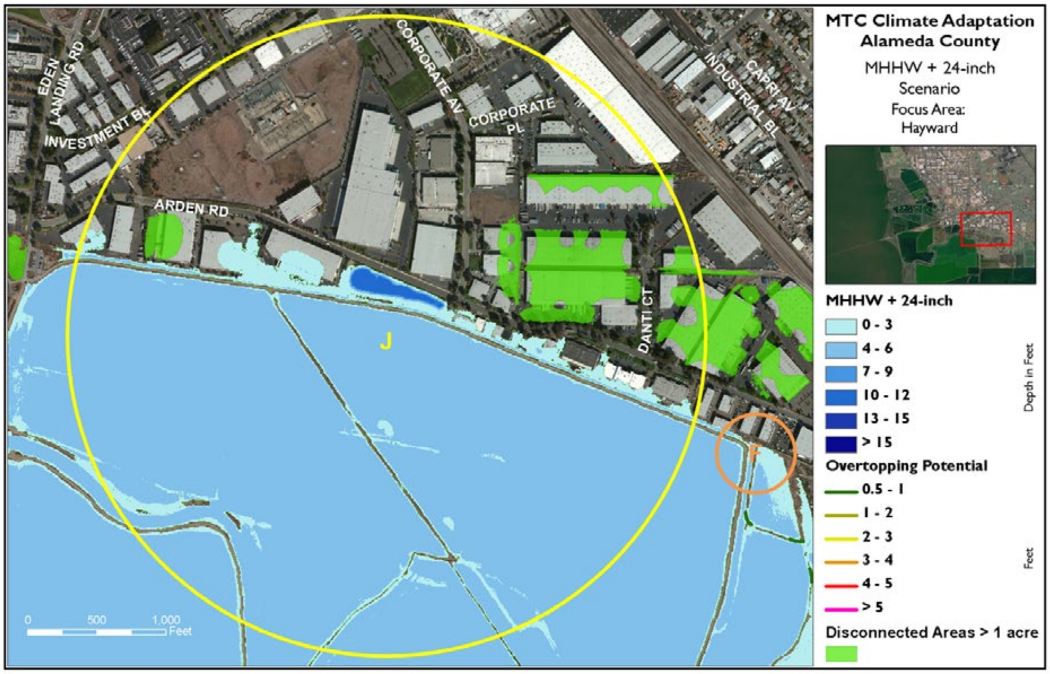
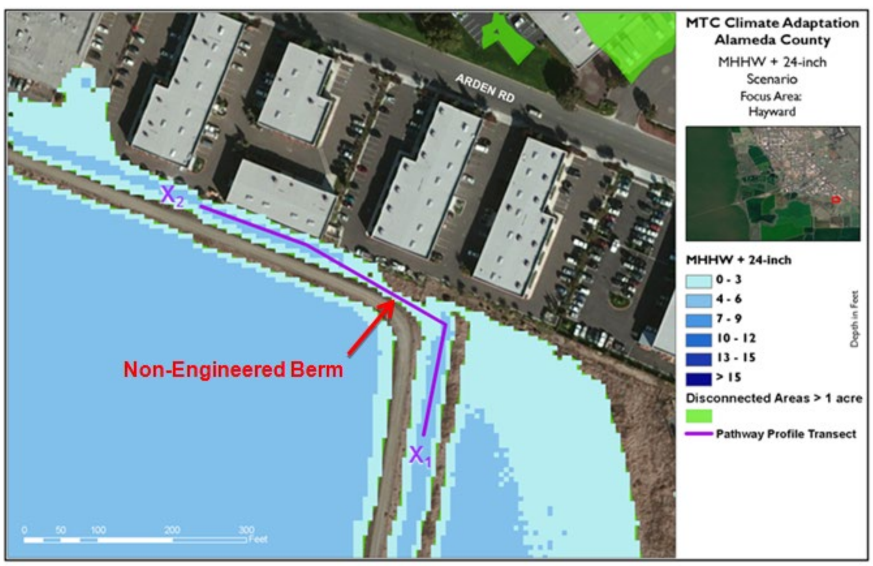
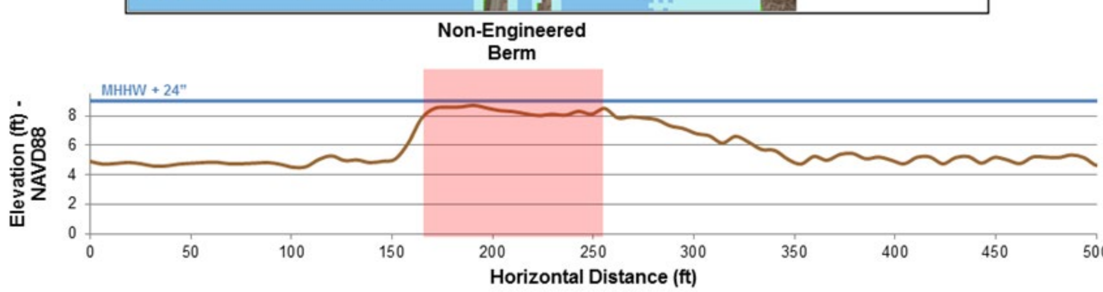


Figure 3-17: Plan and Profile View of Critical Inundation Pathway (Area F) Connecting the Wetland Channel with Inland Inundation Areas





Note: Profile outlined in purple in the plan view. Profile stationing reads from east (X1) to west (X2).

3.5 REFINED EXPOSURE ANALYSIS RESULTS FOR COLISEUM FOCUS AREA

The vulnerabilities of assets in the Coliseum Focus Area were identified based on a review of the inundation mapping, as well as the results of this focus area's exposure to riverine flooding. For this reason this section is organized differently than the other two focus area vulnerability summaries. The vulnerability of the assets is described below for two specific scenarios of sea level rise, accompanied by storm surge and riverine flooding events. These two scenarios represent existing conditions with no sea level rise and future conditions with MHHW +12 inches of sea level rise. A third scenario representing future conditions with 24 inches of sea level rise can be found in the full memo in Appendix B.

3.5.1 EXISTING CONDITIONS (NO SEA LEVEL RISE)

Based on a review of the inundation maps, it is evident that flooding occurs throughout the Coliseum Focus Area even during existing conditions, prior to any increase in daily tide conditions due to sea level rise. This is due to storm surge and riverine flooding events (e.g., peak flow events). The following sections provide detail on the stream channels that are expected to flood, the timing of flooding, the processes that contribute to the flooding during existing conditions and the vulnerability of key assets impacted by this flooding.

3.5.1.1 STREAM CHANNELS EXPECTED TO FLOOD

Damon Slough

- Under existing MHHW tide conditions in the absence of sea level rise, there is no flooding in the Damon Slough channel even at a 100-year peak flow event. Limited flooding occurs during storm surge conditions when a 10-year peak flow event coincides with a 100-year extreme tide.

Arroyo Viejo Creek

- Under existing MHHW tide conditions in the absence of sea level rise, there is limited flooding at one section in the channel during peak flows above the 25-year event, but critical flooding occurs above a 50-year peak flow event. During storm surge conditions at the 10-year extreme tide level, flooding begins at a 25-year peak flow, but extensive flooding occurs during a 50-year peak flow event. Floodwaters in Arroyo Viejo Creek will also travel overland to flood areas adjacent to Damon Slough at the Coliseum park area.

Lion Creek

- Under existing MHHW tide conditions in the absence of sea level rise, flooding occurs at a 50-year peak flow event. During storm surge conditions at or above the 10-year extreme tide level, flooding begins at a 25-year peak flow event, but extensive flooding occurs during a 100-year peak flow event. Flooding is more severe with a 100-year peak flow event during a 10-year extreme tide, than a 10-year peak flow event during a 100-year extreme tide, meaning that the most severe flooding occurs from heavy rainfall events, but flooding is also intensified during storm surge events. It should be noted that channel improvements in Lion Creek upstream of the San Leandro Street crossing were implemented after the calibration of the existing HEC-RAS model, and therefore these changes are not reflected in the existing or future conditions simulations. As a result, the analysis of flooding in this channel is considered conservative.

3.5.1.2 KEY ASSETS IMPACTED BY FLOODING

I-880 Crossing

- No flooding of the I-880 crossing over Damon Slough or adjacent roadway areas is expected to occur during existing conditions. However, further modeling is necessary to verify these findings, since the I-880 crossing was not modeled in HEC-RAS. [31]

Coliseum Complex

- Flooding occurs throughout the Coliseum Complex during MHHW conditions with a 50- to 100-year peak flow rate. Under coastal storm surge, flooding can also occur with a 10-year extreme tide combined with a 25-year peak flow event. Flooding at low-lying areas at the parking lot is not expected to occur directly from Damon Slough, but via overland flow pathways from Arroyo Viejo Creek during these peak flow events. The most extensive flooding in the parking lot area is expected during a 100-year extreme tide level combined with a 10-year peak flow event.

Coliseum Amtrak Station / Union Pacific Railroad

- In the absence of storm surge, the Coliseum Amtrak Station and Union Pacific rail corridor is vulnerable to flooding beginning at a 50-year peak flow event. During coastal storm surge, flooding can also occur with a 100-year extreme tide combined with a 25-year peak flow event. Although the Amtrak Station passenger platform may not be flooded during all scenarios, the operations of this asset are sensitive to flooding of the surrounding railway and any exposure of the electrical components to floodwaters. The rail crossings over Arroyo Viejo and Lion Creek are especially vulnerable to flooding during all scenarios, but the crossing over Arroyo Viejo creek was not modeled in HEC-RAS (see Footnote 15), and this constriction should be included if more detailed modeling work is conducted.

Coliseum BART Station

- The Coliseum BART station is the most vulnerable during rainfall runoff events, and is exposed to flooding from Lion Creek via an overland flow pathway along San Leandro Street and also just north of San Leandro Street. Although the passenger platform and service corridor is elevated, there are existing power utilities and pedestrian access points located at existing ground elevations, which are vulnerable to exposure prior to the BART station itself. Under existing MHHW conditions, flooding at ground elevations can occur a 100-year peak flow event. During coastal storm surge, more severe flooding can occur with a 10-year extreme tide combined with a 100-year peak flow event. Storm surge conditions in the Bay have less of an impact in this area than flooding from watershed runoff. Flooding of the adjacent roadways and parking lot can occur during scenarios earlier than a 100-year peak flow event without storm surge, and may cause disruptions that will impact the overall level of service of the system.

Oakland Airport Connector

- Although the pedestrian area of the new Oakland Airport Connecter is elevated, there are vulnerable power facilities and utilities located at ground elevations. The location of the new Oakland Airport Connector is vulnerable to flooding during a 50-year peak flow event in the

[31] The HEC-RAS model was leveraged from an existing source, and while minor modifications were made to it to support the analysis, a significant effort was not invested to add additional cross sections or to account for any potential updates needed to more accurately represent the current system. ACFCWCD is currently in the process of updating their hydrologic and hydraulic models in this area (Oakland, ACFCWCD Zone 12), and updated models are expected to be available within a two-year timeframe.

surrounding channels, even in the absence of storm surge conditions. During coastal storm surge, overland flooding can also occur with a 10-year extreme tide combined with a 25-year peak flow event. The Airport Connector railway eventually enters below grade elevations near Doolittle Drive outside of the Coliseum Focus Area, but within the ART Alameda sub-region area. Flooding at the locations where the railway enters and exits below grade elevations will cause disruptions in service to the overall transit system in this area and should be investigated further.

3.5.2 FUTURE CONDITIONS (12-INCHES OF SEA LEVEL RISE)

With 12 inches of sea level rise, flooding will be increased in all areas. In some areas, flooding will occur more frequently with smaller peak flow events under the same coastal storm surge conditions. The areas that are the farthest upstream from the tidal influence will see the least impact from rising tides, but will still experience worsened flooding due to the rising base-flow elevation in the stream channels. The following sections provide detail on the stream channels that are expected to flood, the timing of flooding, the processes that contribute to the flooding, and the vulnerability of key assets impacted by this flooding.

3.5.2.1 STREAM CHANNELS EXPECTED TO FLOOD

Damon Slough

- Damon Slough is still able to convey the 100-year peak flow event within the channel in the absence of storm surge conditions in the Bay during MHHW+ 12 inches of sea level rise. However, flooding now occurs during smaller and more frequent storm surge events – a 10-year extreme tide when combined with a 10-year peak flow event. The greatest influence on downstream water levels is storm surge, so the addition of 12 inches of sea level rise on the 100-year extreme tide level can flood these areas by a depth greater than 1-foot. The upstream portions of Damon Slough are flooded by less than 1-foot with either a 10-year peak flow during a 100-year extreme tide or a 100-year peak flow during a 10-year extreme tide, meaning that any combination of riverine and storm surge can now cause flooding during the 12 inch sea level rise scenario. This was not the case with no sea level rise. The primary driver for flooding in the downstream reaches are extreme tide levels during storm surge conditions, and the primary driver for flooding in the upstream reaches are peak flows during rainfall runoff events.

Arroyo Viejo Creek

- During MHHW conditions, Arroyo Viejo Creek will experience flooding during a 50-year peak flow event (the same as existing conditions with no sea level rise), but with MHHW+ 12 inches of sea level rise the downstream portions will experience greater depths of flooding. Under coastal storm surge with MHHW+ 12 inches of sea level rise, Arroyo Viejo Creek floods during a 10-year extreme tide level combined with a 10-year peak flow event, compared to flooding during existing conditions from a 10-year extreme tide combined with a 25-year peak flow event. Although adding 12 inches of sea level rise at the downstream boundary does not translate to an increase of 12 inches in the upstream base-flow elevation in this reach, the tidal influence is strong enough to create additional flooding in upstream areas during storm surge conditions.

Lion Creek

- In Lion Creek, MHHW+12 inches of SLR allows flooding to occur more frequently with smaller peak flow events. During MHHW conditions, areas adjacent to Lion Creek now flood at a 25-year peak flow event, and with coastal storm surge, flooding now occurs at a 10-year extreme tide level combined with a 10-year peak flow event. Although adding 12 inches of sea level rise at the downstream boundary does not translate to an increase of 12 inches in the upstream base-flow elevation in this reach, the tidal influence is strong enough to create additional flooding in upstream areas during storm surge conditions.

3.5.2.2 KEY ASSETS IMPACTED BY FLOODING

I-880 Crossing

- No flooding over the I-880 roadway is expected to occur unless there are elevated Bay water levels during storm surge conditions. Flooding at I-880 due to MHHW+ 12 inches of sea level rise is expected to occur when a 100-year extreme tide level is combined with a 10-year peak flow rate. The deck of the bridge crossing over Damon Slough and portions of the adjacent roadways are vulnerable to flooding during this scenario.

Coliseum Complex

- Flooding occurs throughout the Coliseum Complex during MHHW conditions with a 50-year peak flow rate, the same as existing conditions with no sea level rise. Flooding at low-lying areas at the parking lot is from overland flow pathways from Arroyo Viejo Creek during these peak flow events. With MHHW+ 12 inches of sea level rise flooding also comes directly from overtopping over Damon Slough starting from a 10-year extreme tide combined with a 25-year peak flow event. The most extensive flooding in the parking lot area is expected during a 100-year storm surge combined with a 10-year peak flow event.

Coliseum Amtrak Station / Union Pacific Railroad

- With MHHW+ 12 inches of sea level rise, the Coliseum Amtrak Station and Union Pacific rail corridor are exposed to flooding starting at a 50-year peak flow event during MHHW conditions, the same as with no sea level rise. With coastal storm surge, flooding can also first occur during a 10-year extreme tide when combined with a 25-year peak flow event, the same as with no sea level rise.

Coliseum BART Station

- Flooding can occur during peak flows of a 100-year event under MHHW + 12 inches of sea level rise, the same as with no sea level rise. With coastal storm surge, flooding can also first occur during a 10-year extreme tide when combined with a 10-year peak flow event. This is a smaller peak flow than the 25-year peak flow required to cause flooding with a 10-year extreme tide with no sea level rise.

Oakland Airport Connector

- Under MHHW+ 12 inches of sea level rise, the same components of the new Oakland Airport Connector that are exposed to flooding under existing conditions will be impacted (see Section 3.5.1.2), but at a greater depth.

3.6 RESULTS OF REFINED VULNERABILITY ANALYSIS

In addition to the inundation and flooding exposure analysis described in Sections 3.1-3.5, the Technical Team identified specific physical, functional, informational and governance vulnerabilities for each of the core and adjacent assets which were then further refined during the adaptation strategy development process (see Chapter 4). This classification system was developed as part of the ART project[32] in order to sort and characterize vulnerabilities to make it easier to develop robust adaptation responses. The classifications are defined below, and examples of the vulnerabilities and refinements provided for each:

[32] http://www.adaptingtorisingtides.org/wp-content/uploads/2013/09/ARTSubregionalVuln-20130717-FINAL.pdf

- ***Informational vulnerability*** - Challenges to obtaining information necessary to understand or resolve issues.
    - Damon Slough Bridge: The capacity of the Damon Slough Bridge to contain future extreme water levels is unknown and further studies are needed to understand how these bridges may or may not be of adequate capacity as sea level and groundwater rises.
    - Further refinement of the vulnerability: Need to estimate the asset's pressure flow scour and if necessary evaluate structural integrity to determine if it is vulnerable to scour.

- ***Governance vulnerability*** - Governance characteristics relating management, permitting, financing and funding availability that increase vulnerability or create barriers to implementing adaptation options
    - SR 92: Work along the SR 92 corridor requires coordination with a number of regulatory agencies including BCDC, CADFW, RWQCB, and USACE because of its location between tidal marshes and managed ponds. The amount of coordination necessary can delay necessary maintenance or improvements to address future storm events and sea level rise impacts.

- ***Functional vulnerability*** - Functional aspects of an asset that make it very sensitive to impacts or severely limit the region's adaptive capacity.
    - I-880 from 7^{th} Street to the Toll Plaza: There is limited redundancy for car or bus (AC Transit) commuters that rely on this segment of I-880 to access the Bay Bridge or I-80 West. Alternative routes such as I-980 to I-580 or West Grand to the toll plaza have limited additional capacity and would not be able to provide the same level of service necessary if this segment of I-880 was disrupted.
    - Further refinement of the vulnerability: Commuters accessing the Bay Bridge would access via the flyover roadway to the Toll Plaza. Bridge and through traffic would face disruption at lower elevations south of the flyover and at Toll Plaza. Through traffic would access other N/S interstates to avoid inundated areas. Bridge traffic would use Richmond/Golden Gate or SR 92 bridges to access the peninsula. Passenger travel can also be accommodated by additional transit service. The area is well-served by multiple transit routes and ferries that provide a limited level of redundancy; these agencies have mutual aid agreements and participate in emergency planning.

- ***Physical vulnerability*** - Physical aspects of an asset that make it very sensitive to impacts or severely limit its adaptive capacity.
    - BART Coliseum: Train control equipment is at-grade and housed, but was not constructed to be exposed to water or salinity and therefore is not likely to be flood resistant.
    - Further refinement of the vulnerability: The control room includes electronic equipment for train control, communications, and station security. Inundation by storm surge would lead to loss of equipment function and cripple BART services at the station.

Both the original and the refined description of the vulnerabilities for each asset and its components can be found in the compendium of adaptation strategies in Appendix C, organized by focus area.

Adaptation Strategy Development and Selection

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4. ADAPTATION STRATEGY DEVELOPMENT AND SELECTION

4.1 SUMMARY

This chapter provides an overview of how a compendium of 124 adaptation strategies were developed for assets and asset components on the basis of the vulnerabilities identified in the previous stage of this project (see Chapter 3 for details on the vulnerability assessment). This chapter then describes the prioritization process that was used to select a final list of 5 strategies, for which detailed descriptions have been developed (see Chapters 5-8). The prioritization process consisted of the following two intermediate steps:

- A screening exercise to identify a short-list of 17 strategies from the master-list of 124 strategies,
- A qualitative assessment to identify the final 5 strategies from the short-list of 17 strategies.

Finally, this chapter describes the baseline scenarios which show how the identified vulnerable assets and asset components in each focus area would be affected by various magnitudes of sea level rise and storm surge if no actions are taken to adapt to these climate change variables. The baseline scenarios were then used to evaluate the effectiveness of the 5 final adaptation strategies, by comparing the expected performance of the adaptation strategies against the baseline scenarios for each focus area.

4.2 DESCRIPTION OF ADAPTATION STRATEGY DEVELOPMENT BY VULNERABILITY TYPE

As a first step in the adaptation strategy and development process, a set of 124 potential adaptation strategies were developed that could be used to address existing vulnerabilities in the three focus areas. The strategies were organized into the following three broad categories:

- Core Asset Strategies - to manage or mitigate specific core asset vulnerabilities within each of the three focus areas
- Focus Area-wide Strategies - to manage or mitigate core and adjacent asset vulnerabilities through implementation of a large-scale intervention (e.g., shoreline protection) within each of the three focus areas
- Agency-specific Strategies - to manage or mitigate internal agency management-related and information-related vulnerabilities (applicable across all focus areas)

Within each of these strategy categories, sub-categories were created, in order to clearly identify what type of vulnerability the strategy was addressing. The sub-categories, organized by the type of vulnerability which the strategy addressed are listed below, along with an example of each:

- Physical Strategies: Strategies that address physical vulnerabilities of assets
    - o Example: The construction of a levee on both sides of a highway segment to prevent physical damage to the segment.
- Functional Strategies: Strategies that address the functional vulnerabilities of assets

Example: The construction of a levee on both sides of a highway segment to preserve the functionality of the segment. (Note: the same example is provided for physical and functional strategies, as in this case addressing the physical vulnerability will also improve the functional vulnerability.

- Informational Strategies: Strategies that provide improved understanding of the vulnerabilities of assets arising from the current lack of information
    - Example: Conducting a saltwater and groundwater modeling study to understand the impact of sea level rise on local groundwater hydrology in the Bay Bridge and Coliseum Focus Areas.
- Governance Strategies: Strategies that address governance-related vulnerabilities of assets
    - Example: Convening a working group of multiple agencies to collaboratively address climate change-related vulnerabilities to infrastructure owned and operated by the agencies.

Using this categorization structure, a compendium of 124 strategies was developed, which contains the following information for each strategy. The full compendium of 124 strategies can be found in Appendix C.

- **Strategy type**: This field specifies the strategy type, as categorized by the type of vulnerability being addressed by the strategy.
- **Strategy name and description**: This field provides a description of the specific actions that the strategy is proposing.
- **Assets protected by strategy**: This field provides a list of all the vulnerable assets and asset components that will be protected by the strategy.
- **Vulnerabilities addressed by strategy**: This field describes the vulnerabilities identified for the assets and asset components, as developed by the Technical Team, and refined by the Consultant Team.
- **Point of intervention**: This field identifies the type of mechanism that would be used to implement the strategy.
- **Partners**: This field identifies the agencies that would be involved in the implementation of the strategy.
- **Timing**: This field indicates the time horizon for the implementation of the strategy, and is a function of the exposure horizon of sea level rise and storm surge, the remaining life of the asset, synergy with planned projects, and implementation coincidence with other proposed strategies.

This compendium of strategies can potentially serve as a resource, not just for the transportation assets that were evaluated in this project, but also for transportation assets regionally and nationwide.

4.3 STRATEGY PRIORITIZATION PROCESS

The strategy prioritization process consisted of two intermediate steps, which resulted in the selection of 5 final adaptation strategies, for which detailed implementation route maps were then developed. The two intermediate steps involved:

- A screening exercise to identify a short-list of 17 strategies from the master-list of 124 strategies
- A qualitative assessment to identify the final 5 strategies from the short-list of 17 strategies.

4.3.1 SCREENING EXERCISE

In this step, a set of screening questions were developed in order to identify the strategies that best address the Adaptation Pilot Project objectives and expected outcomes. The screening questions were designed such that the responses to these questions would be in qualitative binary form (“Yes” or “No”). These qualitative binary responses were converted to quantitative scores, such that a response of “Yes” would correspond to a score of “1”, and a response of “No” would correspond to a score of “0”. The 124 adaptation strategies were evaluated on the basis of these screening questions, and the higher the strategies scored, the more favorable they were considered. The screening questions are included in Table 4-1, along with commentary on the underlying assumptions for how adaptation strategies were scored against these questions. Given the multi-agency collaborative nature of this pilot, strategies with multiple co-benefits applicable to multiple areas and requiring agency collaborations were prioritized.

Table 4-1: Screening Questions and Scoring Assumptions

SCREENING QUESTION ID	SCREENING QUESTIONS	UNDERLYING ASSUMPTIONS FOR SCORING PHYSICAL STRATEGIES (ASSET-SPECIFIC AND FOCUS AREA-WIDE)	UNDERLYING ASSUMPTIONS FOR SCORING INFORMATIONAL, GOVERNANCE, AND FUNCTIONAL STRATEGIES
1	Does the strategy address the vulnerability of multiple assets?	All focus area-wide physical adaptation strategies received a score of 1 for this criterion. Asset-specific physical strategies which addressed individual assets or individual asset components received a score of 0. Sub-components of an asset were not considered as individual assets (e.g. the tunnel under the toll plaza and electrical lines serving the tool plaza are sub-components of one asset, which is the toll plaza).	Same assumptions as physical strategies
2	Does the strategy address multiple vulnerabilities of an individual asset (informational, governance, functional, physical)?	If a strategy addressed multiple vulnerabilities of the same kind (e.g. two physical vulnerabilities), then the strategy received a score of 0. However, if a strategy addressed different kinds of vulnerabilities (e.g. one functional vulnerability and one informational vulnerability), then it received a score of 1.	Same assumptions as physical strategies
3	Does the strategy require significant multi-agency coordination to be effective?	Strategies which agencies cannot implement on their own, and require coordination beyond day-to-day operations were assigned a score of 1. Otherwise, they were assigned a score of zero.	Same assumptions as physical strategies
4	Can the strategy be used by more than one agency?	Strategies containing generic recommendations for design or material use, such that they can be implemented by other agencies to address vulnerabilities of other assets (e.g. water-proofing electrical lines) received a score of 1. Strategies that need to be tailored to specific assets were assigned a score of 0.	A strategy received a score of 1 it could be replicated in other areas or if the strategy created a detailed template for a process or a study that could be adopted by other agencies.
5	Does it make sense to start working on this strategy in the next 5 years?	The scoring for this criterion was determined based on the information provided in the Timing column in the compendium. If the Timing column showed immediate or short-term vulnerabilities even at lower magnitudes of sea level rise, or short-term opportunities for action in the next O&M cycle for the asset in question, or short-term opportunities for action due to an adjacent project, the strategy in question was assigned a score of 1. Exceptions to this method were noted.	Same assumptions as physical strategies

Table 4-1: Screening Questions and Scoring Assumptions

SCREENING QUESTION ID	SCREENING QUESTIONS	UNDERLYING ASSUMPTIONS FOR SCORING PHYSICAL STRATEGIES (ASSET-SPECIFIC AND FOCUS AREA-WIDE)	UNDERLYING ASSUMPTIONS FOR SCORING INFORMATIONAL, GOVERNANCE, AND FUNCTIONAL STRATEGIES
6	Does the strategy address multiple transportation modes?	Assets such as BART assets and AMTRAK assets were assumed to be single-mode assets, and were assigned a score of zero. Highways were considered multi-modal and were assigned a score of 1, as both transit and private vehicles can use them. Similarly, assets such as local roads or the bay trail were assigned a score of 1, as they accommodate multiple modes of transport such as motor-vehicles, biking, or walking.	Same assumptions as physical strategies
7	Does the strategy accomplish or contribute to other critical operational objectives (congestion management)?	This criterion helped prioritize strategies with co-benefits for the core operations of the implementing agency. Routine operations and maintenance were not included in the assumed definition of 'critical operational objectives'.	Same assumptions as physical strategies
8	Does the strategy reduce consequences on society/equity? 8a) Homes 8b) Places of work 8c) Recreation areas	Only the strategies that had a direct positive impact on homes, places of work, and recreation areas were assigned a score of 1 – this usually means physical protective strategies.	No informational, governance or functional strategies were found to directly affect society/equity although if they are implemented they would eventually lead to such benefits.
9	Does the strategy provide a positive impact on the environment? 9a) habitat or biodiversity? 9b) water quality?	Only the strategies that had a direct positive impact on habitat/biodiversity and water quality were assigned a score of 1.	No informational, governance or functional strategies were found to directly affect the environment although if they are implemented they would eventually lead to such benefits.
10	Does the strategy provide a positive impact on the economy?	See below	See below
	10a) goods movement?	Only the strategies that had a direct positive impact on goods movement were assigned a score of 1.For transportation assets that aid the movement of goods (e.g. highways, or freight rail), if damage to physical components of transportation assets (including the most minor components) compromises the functional ability of those assets, then strategies to reduce the physical vulnerability of those assets are assumed to reduce impacts on goods movement.	Strategies improving freight operations were assigned a score of 1. The rest were assigned a score of 0.

Table 4-1: Screening Questions and Scoring Assumptions

SCREENING QUESTION ID	SCREENING QUESTIONS	UNDERLYING ASSUMPTIONS FOR SCORING PHYSICAL STRATEGIES (ASSET-SPECIFIC AND FOCUS AREA-WIDE)	UNDERLYING ASSUMPTIONS FOR SCORING INFORMATIONAL, GOVERNANCE, AND FUNCTIONAL STRATEGIES
	10b) commuter movement?	Only the strategies that had a direct positive impact on commuter movement were assigned a score of 1. For transportation assets that aid the movement of passengers, if damage to physical components of transportation assets (focus on major transportation components) compromises the functional ability of those assets, then strategies to reduce the physical vulnerability of those assets are assumed to reduce impacts on commuter movement.	Strategies benefiting operations and enabling risk reduction were assigned a score of 1. The rest were assigned a score of zero.

4.3.1.1 SCREENING EXERCISE RESULTS

Following the screening exercise, a short-list of 17 adaptation strategies was selected from the 124 strategies for further evaluation. In general, the strategy selection was based on how the strategies scored in the screening exercise. However, there were some exceptions to this method. For example, there was an effort to strike a balance such that at least one strategy was selected for each of the focus areas evaluated in this project. Furthermore, there was also an effort to ensure that the selected strategies addressed different types of vulnerability (i.e., physical, functional, informational, and governance-related vulnerabilities). As a result of such special considerations, some strategies which scored highly in the screening exercise were not prioritized for further evaluation. An example of one such strategy is *Updating and Maintaining the San Francisco Bay Area Regional Transportation Emergency Management Plan (RTEMP)* which was considered as a solution to address multiple functional vulnerabilities. This strategy was not selected for further evaluation despite scoring highly in the screening exercise, because the Metropolitan Transportation Commission (MTC) already has a process in place to regularly review and update the RTEMP; and the next update is expected to take into account the impacts of sea level rise and storm surge. Other strategies were not advanced as they were seen to be more straightforward strategies that did not need further research or analysis as part of this project (e.g., using waterproofing materials or concrete sealants to protect assets against the impacts of saltwater intrusion and corrosion).

Conversely, some strategies were selected for further evaluation despite not scoring highly in the screening exercise, as it was determined that the favorability of said strategies was not accurately represented in the screening exercise due to the nature of the questions. For example, the *BART Planning Process Update* [33]strategy was included even though BART is a single-mode transit agency and therefore received one less point than similarly vulnerable highway assets during the screening exercise. In addition, it was felt that other transportation agencies could also benefit from this type of strategy and so the focus of the strategy was altered so that it could be applicable to any transportation agency.

[33] Note this strategy was later renamed to *Mainstreaming climate change risk into transportation agencies* to reflect its relevance to all transportation agencies.

The final set of 17 strategies that were selected on the basis of the above considerations is listed in Table 4-2. The rows highlighted in green contain the strategies that did not necessarily score highly in the screening exercise, but were recommended for inclusion and further evaluation by the Technical Team based on special considerations. The rows highlighted in blue contain the strategies that scored highly in the screening exercise, but were not considered for further evaluation due to special considerations. The white rows indicate the strategies that scored highly and were recommended for further evaluation. The column titles in Table 4-2 are described below:

- **Strategy Type:** Physical, Informational, Governance, or Focus-area-based (Note: no functional strategies were selected for further evaluation, as it was concluded that any focus area-wide strategies meant to address physical vulnerabilities of assets will automatically address the functional vulnerabilities of those assets. In addition, the asset-specific functional strategies in the master-list of 124 strategies were recommending actions that were likely to take place regardless of the efforts of this project, and as a result, they were not selected for further evaluation).
- **Focus Area:** Bay Bridge, Coliseum, or Hayward
- **Agency:** BART or Caltrans (This table field is intended to highlight 'Agency specific' strategies, and is applicable to only 2 strategies.)
- **Asset:** List of assets protected by strategy. For focus area-wide physical strategies, there are multiple assets protected (both core and adjacent).
- **Strategy Title:** A short title describing the strategy. For a detailed description of the strategies, see Appendix C, which contains a compendium of all 124 strategies, in which the highest scoring strategies are highlighted in a blue background
- **Strategy Score:** The total score assigned to the strategy per the screening questions.

4.3.1.2 SUMMARY OF STRATEGIES SELECTED FOR FURTHER EVALUATION

The following strategies 17 strategies were selected for further evaluation:

Governance Strategies

1. **BART planning process update / Mainstreaming climate change risk into transportation agencies**
   This strategy recommends a step-by-step process (roadmap) that any transit or transportation agency can follow to adapt to climate change in the most cost effective way, by mainstreaming adaptation into the agency's planning processes, and demonstrates how this roadmap can be applied to agencies like BART and Caltrans.
2. **Caltrans coordination with permitting agencies around SR 92 (Hayward)**
   This strategy recommends creating a working group of relevant agencies to identify ways to streamline permitting processes and avoid delays in future adaptation project planning and implementation. A key outcome of this strategy would be to determine what an overarching permitting strategy might entail for projects in the SR 92 corridor, to best address permitting needs in the long run.
3. **Inter-agency coordination (Bay Bridge)**
   This strategy recommends that agencies which own or operate assets in the Bay Bridge Focus Area form a working group to collaboratively address climate change related vulnerabilities of infrastructure in the area. The working group could include BATA, Caltrans, the City of Oakland, and the city of Emeryville.

Table 4-2: List of 17 Selected Strategies for Further Evaluation

STRATEGY TYPE	FOCUS AREA	AGENCY	ASSET	STRATEGY TITLE	TOTAL SCORE
Functional	Bay Bridge	Not Specific to one agency	I-880 7th Street to the Toll Plaza	Enhance ITS infrastructure*	9
			1-80 / I-580 Powell St. to Toll Plaza		
			BART assets - general for focus area		
Functional	Coliseum	Not Specific to one agency	BART Oakland Connector (OAC) General	Update and maintain RTEMP*	9
			Oakland Coliseum AMTRAK Station		
	Bay Bridge		BART assets - general for focus area		9
			I-880 7th Street to the Toll Plaza		
			1-80 / I-580 Powell St. to Toll Plaza		
			East Portal Transbay Tube		
	Coliseum		I-880 from Coliseum Way to 98th Avenue		9
			Coliseum BART Station		
			BART Oakland Connector (OAC) General		
	Hayward`		SR 92 causeway between Toll Plaza and Mainland		9
Governance	Bay Bridge and Coliseum	BART	Multiple (both core and adjacent)	BART planning process update**	3
Governance	All	Caltrans	All Caltrans assets	Asset Management Database Development*	5
Governance	All (particularly Hayward)	Caltrans	All Caltrans assets	Adaptation strategy coordination with permitting agencies	5
Governance	Bay Bridge	Not Specific to one agency	I80, Bay Bridge toll plaza and bike path (as a collection of assets)	Inter-agency coordination (all agencies)	5
Governance	Bay Bridge	Not Specific to one agency	I-80/I-580 segment between 40th St and Powell St (supported aerial sections)		5
Governance	All	Caltrans	All Caltrans assets	Incorporation of sea level rise considerations during asset rehabilitation	5
Informational	Hayward	Not Specific to one agency	SR 92 causeway between Toll Plaza and Mainland	Drainage study**	4
Informational	All	Caltrans	All Caltrans assets	Geo referencing of Asset Management Database*	5
Informational	Bay Bridge and Coliseum	BART	Multiple (both core and adjacent)	Groundwater and saltwater Intrusion modeling	5
Physical	Bay Bridge	Not Specific to one agency	Drainage area around I-80 segment between 40th St and Powell St	Drainage system modifications	6

Table 4-2: List of 17 Selected Strategies for Further Evaluation

STRATEGY TYPE	FOCUS AREA	AGENCY	ASSET	STRATEGY TITLE	TOTAL SCORE
			Drainage area around I-880 segment between 7th St and 40th St		
Physical	Bay Bridge Coliseum	Not Specific to one agency	I-880 segment between 7th St and 40th St (supported aerial sections) I-880 Damon Slough Bridge Elmhurst Creek Bridge	Concrete Sealants*	6
Physical	Bay Bridge	Not Specific to one agency	Drainage area around I-80 segment between 40th St and Powell St Drainage area around I-880 segment between 7th St and 40th St	Drainage System Modifications*	6
Physical	Bay Bridge Hayward	Not Specific to one agency	Power-lines in tunnel under toll plaza SR 92: San Mateo/Hayward Bridge Toll Plaza (1st and 2nd approach) Communication/Power Lines	Waterproofing Junctions*	6
Physical	Coliseum	Not Specific to one agency	I-880 Damon Slough Bridge	Flow restriction reduction	6
Physical	Hayward	Not Specific to one agency	SR 92 causeway between Toll Plaza and Mainland	Levee installation	6
Focus-area-based	Bay Bridge	Not Specific to one agency	Multiple (both core and adjacent)	Offshore breakwater installation*	9
Focus-area-based	Bay Bridge	Not Specific to one agency	Multiple (both core and adjacent)	Artificial dune installation*	9
Focus-area-based	Coliseum	Not Specific to one agency	Multiple (both core and adjacent)	Damon Slough levee installation*	9
Focus-area-based	Coliseum	Not Specific to one agency	Multiple (both core and adjacent)	Damon Slough tide-gate installation*	9
Focus-area-based	Hayward	Not Specific to one agency	Multiple (both core and adjacent)	Maintenance of existing shoreline alignment*	9
Focus-area-based	Coliseum	Not Specific to one agency	Multiple (both core and adjacent)	Damon Slough living levee (Bay Farm Island) installation:	10
Focus-area-based	Bay Bridge	Not Specific to one agency	Multiple (both core and adjacent)	Natural/engineered protection	10
Focus-area-based	Hayward	Not Specific to one agency	Multiple, including Bay Trail and the connection to the SR 92 bike/pedestrian bridge	Marsh management: cooperative land retreat	11

* These strategies scored highly in the screening exercise, but were not selected for further evaluation as per the recommendations of the Technical Team.

** These strategies were included as per the recommendations of the Technical Team, but did not necessarily score as highly in the screening exercise.

4. **Incorporation of sea level rise considerations during infrastructure rehabilitation (Agency-wide)**
   This strategy recommends that Caltrans put in place a requirement for sea level rise impacts to be considered prior to the rehabilitation of existing agency owned infrastructure. Under this strategy, Caltrans' existing guidance on sea level rise considerations could be extended to cover rehabilitation plans for vulnerable existing assets. Considerations may include how sea level rise impacts asset life, and how vulnerability to sea level rise can be minimized for existing assets. Other considerations may include the costs and benefits of design alternatives that would provide protection from sea level rise.

Informational Strategies

5. **Groundwater and Saltwater Intrusion Modeling (Bay Bridge and Coliseum)**
   This strategy recommends agencies partner with appropriate academic institutions to start research to better understand the impact sea level rise would have on local groundwater hydrology. The research would provide data applicable to drainage, saltwater intrusion, and seismic hazard. The data would be used by engineers and planning staff to better evaluate asset vulnerability.
6. **SR 92 Drainage Study (Hayward)**
   This strategy recommends that Caltrans collaborate with the City of Hayward and ACFCWCD to conduct a study of the existing drainage system/capacity in the Hayward Focus Area in order to understand the existing capacity of the system and to inform the drainage opportunities and constraints associated with the suite of potential physical adaptation strategies.

Physical Strategies

7. **Drainage system modifications (Bay Bridge)**
   This strategy recommends that the City of Oakland and Alameda County collaborate to implement drainage system modifications in the Bay Bridge Focus Area. Modification options may include a) realigning drainage pipes to the minimum slope required to accommodate the design flow and raising the discharge points, b) rerouting drainage pipes to a shorter route to a discharge point, allowing that new discharge point to be higher in elevation, c) adding parallel drainage system as backup for the reduced flow rate in the existing system, or d) install pumps.
8. **Flow Restriction Reduction (Coliseum)**
   This strategy recommends measures to reduce the restriction to water flows in Damon Slough. Measures include a) widening Damon Slough under and downstream of bridge via partial channelization of creek with concrete walls or gabion type of earth retaining structure, or 2) adding culverts under Hwy 880 to provide for a supplemental flow path for the slough at times of high flows.
9. **Levee installation either side of the SR 92 (Hayward)**
   This strategy recommends the installation of an engineered levee on either side of SR 92, with variable habitat on the backside of the levee. Under this strategy, the SR 92 segment would remain at existing grade and ultimately below flood level, fully dependent on levee structures for protection.

Focus Area Strategies

10. **Bay Bridge Focus Area (North-side): Artificial dunes[34] installation**
    This strategy recommends constructing artificial dunes along the entire length of the low-lying section north of the Bay Bridge touchdown, to retain the habitat value of that area, while providing protection to the 1-80 HWY.

[34] This strategy later was changed to a living levee strategy after some initial analysis was undertaken.

11. **Bay Bridge Focus Area (North-side): Breakwater installation**
This strategy recommends constructing an offshore breakwater north of the Bay Bridge touchdown. This would not mitigate sea level rise, but it would reduce storm surge and wave impacts, provide protection to the I-80 highway section and the adjacent habitats (marsh, dunes, and pocket sandy beaches) and also provide protection to the Emeryville Crescent Marsh area. This strategy could work in tandem with other focus area-wide physical strategies.

12. **Bay Bridge Focus Area (North-side): Shoreline protection**
This strategy recommends constructing a designed structure (such as an engineered berm with rock revetment which also maximizes the use of natural elements as much as possible to maintain the link with the valuable habitats in this area) alongside the road corridor to the north of the I-80 bridge.

13. **Coliseum Focus Area: Damon Slough tide gate installation**
This strategy recommends installing a tide gate perpendicular to Damon Slough, in order to block Damon Slough just west of I-880, which would still allow the slough to drain during flood events and drop its sediment load behind the barrier, but deny sea level rise to the Coliseum area.

14. **Coliseum Focus Area: Damon Slough levee installation**
This strategy recommends constructing a levee along either side of Damon Slough from east of I-880 to San Leandro Street to protect adjacent facilities and properties from future high tide levels.

15. **Coliseum Focus Area: Damon Slough living levee installation**
This strategy recommends using a combination of natural restoration and aesthetic levees/walls/berms along the length of Damon Slough to protect adjacent facilities and properties from future high tides.

16. **Hayward Focus Area: Marsh Management/Cooperative landward retreat**
This strategy recommends a collective management approach for agencies which provide various services (e.g. flood control, wildlife habitat, recreation, and wastewater treatment) in the Hayward Focus Area. This approach involves the collective adoption of actions to adapt to sea level rise in a way that maximizes the use of the land in the focus area at the given time. Such actions may include protective measures in the near term, and gradual land retreat or habitat restoration in the long term.

17. **Hayward Focus Area: Maintenance of existing shoreline alignment**
This strategy recommends maintaining the current shoreline alignment and associated habitat values for as long as is practical. Maintaining the existing shoreline may require measures such as maintaining berms, and periodically raising the bayside berm crest elevation. This is a short/medium term strategy, and would need to be supplemented with long-term solutions to continue providing protection to assets in the Hayward Focus Area.

4.3.2 QUALITATIVE ASSESSMENT

In this step, the 17 adaptation strategies short-listed in the screening exercise were evaluated further via a qualitative assessment. A set of criteria was developed for the qualitative assessment in order to allow a comparison of the financial, social, environmental, and governance-related performance of the 17 strategies. A qualitative ordinal ranking system was used for most of the criteria to remove false precision of estimated performance metrics. For some criteria, quantitative information was used when it was on hand, but new quantitative data were not sought for this qualitative assessment. Each criteria category (i.e. financial, social, environmental, and administration-related) was weighted equally in terms of its contribution to the overall favorability of a strategy. The goal was not to select the highest scoring strategy, but to evaluate the trade-offs between the different criteria categories, and select strategies that that were the most balanced in terms of meeting criteria in all four categories.

Table 4-3 shows the color-coded range of ordinal ranks that were used for the assessment criteria. This ranking system allowed for a qualitative comparison of the 17 strategies without the need for a total quantitative score.

Table 4-3: Range of Ordinal Ranks

ORDINAL RANKS	RANK NOTATION	COLOR CODE
Significantly Positive	++	
Positive	+	
Neutral	0	
Negative	-	
Significantly Negative	--	
Not Applicable	NA	
To Be Determined	TBD	

Table 4-4 lists the criteria used for the qualitative assessment, and explains how the above ordinal ranking system was applied to the criteria. In cases where the criteria were not relevant to the strategies, the strategies were ranked as 'Not Applicable (NA)'. In cases where the strategies were not evaluated by the criteria due to the qualitative nature of this assessment, the strategies were ranked as 'TBD'.

4.3.2.1 QUALITATIVE ASSESSMENT RESULTS

The results of the qualitative assessment are presented in summarized pie-charts in Figure 4-1, Figure 4-2, Figure 4-3, and Figure 4-4. The color coding in the pie-charts corresponds with the color coded range of ordinal ranks in Table 4-3. The labels in the pie-charts correspond with the Criteria ID in Table 4-4. The detailed qualitative assessment for each of the 17 strategies can be found in Appendix D.

Financial criteria are indicated by "$$". Social criteria are indicated by walking figures. Environmental criteria are indicated by a leaf. Governance-related criteria are indicated by an anchor.

In addition to the results of the qualitative assessment, the following supplementary guidelines were developed in order to ensure a fair evaluation of strategies that may not have ranked highly in the qualitative assessment due to the nature of the assessment criteria:

General Evaluation Guidelines:

- A standardized qualitative assessment can be a good way to evaluate the performance of strategies, but it should always be supplemented by the local knowledge and expertise of stakeholders and agencies.
- It is better to compare strategies within each category (informational, asset-specific physical, governance, and focus area-wide physical) rather than across categories.
- Given that focus area-wide physical strategies offer physical protection on a regional scale, they should be prioritized over asset-specific physical strategies. Therefore, picking a focus area-wide physical strategy over an asset-specific physical strategy is justifiable.
- Functional vulnerabilities are often addressed by physical or focus area –wide strategies.
- An attempt should be made to select strategies which can also achieve the objectives of the strategies that weren't selected for further evaluation. For example, there is a strategy recommending a drainage study near SR 92, and one recommending a drainage system study and modifications near the Bay Bridge. If there is potential for one area to learn from another, select the strategy with greater benefits.

Table 4-4: Qualitative Assessment Criteria

<table>
<tr><th>CRITERIA ID</th><th>PROPOSED CRITERIA</th><th colspan="3">RANKING LOGIC</th></tr>
<tr><th></th><th>Financial Criteria</th><th colspan="3">Ordinal Ranking Rationale</th></tr>
<tr><td rowspan="7">F1</td><td rowspan="7">Marginal capital/program cost of adaptation strategy relative to the cost of no action</td><td colspan="2">Project Cost</td><td>Rank</td></tr>
<tr><td colspan="2"><$100K</td><td>++</td></tr>
<tr><td colspan="2">$100K - $500K</td><td>+</td></tr>
<tr><td colspan="2">$500K - $1M</td><td>0</td></tr>
<tr><td colspan="2">$1M - $10M</td><td>-</td></tr>
<tr><td colspan="2">>$10M</td><td>--</td></tr>
<tr><td colspan="3">The range of capital costs was from $40,000 - $20,000,000</td></tr>
<tr><td rowspan="6">F2</td><td rowspan="6">Annual operating and maintenance cost of adaptation strategy relative to the cost of no action</td><td colspan="2">Strategy Type</td><td>Rank</td></tr>
<tr><td colspan="2">Informational strategies</td><td>NA</td></tr>
<tr><td colspan="2">Governance strategies</td><td>+</td></tr>
<tr><td colspan="2">Asset-specific Physical strategies</td><td>-</td></tr>
<tr><td colspan="2">Focus area-wide Physical strategies</td><td>--</td></tr>
<tr><td colspan="3">A cost range was not quantified for this qualitative assessment, but in general it was assumed that regional structural solutions will have a higher maintenance cost (even when averaged out annually) compared to informational or governance strategies.</td></tr>
<tr><td rowspan="6">F3</td><td rowspan="6">Duration / life span of strategy</td><td colspan="2">Strategy Type</td><td>Rank</td></tr>
<tr><td colspan="2">Focus area-wide Physical strategies</td><td>++</td></tr>
<tr><td colspan="2">Governance strategies</td><td>++</td></tr>
<tr><td colspan="2">Asset-specific Physical strategies*</td><td>+</td></tr>
<tr><td colspan="2">Informational strategies</td><td>NA</td></tr>
<tr><td colspan="3">*While most asset-specific physical strategies were ranked as positive in terms of their lifespan, the asset-specific physical strategy recommending the SR 92 levee was ranked as significantly positive due to the long lifespan of levees. In general, the assumption is that the longer the duration, the better the strategy, unless the duration is not applicable to a strategy.</td></tr>
<tr><td rowspan="5">F4</td><td rowspan="5">Implementation coincidence of strategy with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes</td><td colspan="2">Potential for Integration</td><td>Rank</td></tr>
<tr><td colspan="2">High</td><td>++</td></tr>
<tr><td colspan="2">Moderate</td><td>+</td></tr>
<tr><td colspan="2">None</td><td>-</td></tr>
<tr><td colspan="3">In general, the integration potential was assumed to be high or moderate for strategies that focus on modifications to existing structures, studies, or processes. Strategies focusing on creating new structures, studies, or processes were assumed to have no integration potential.</td></tr>
<tr><td rowspan="5">F5</td><td rowspan="5">Ability of strategy to maintain operational continuity</td><td>Transport Mode</td><td>Indicator</td><td>Rank</td></tr>
<tr><td>BART</td><td>All BART ridership</td><td>++</td></tr>
<tr><td rowspan="2">Private</td><td>AADT* >200,000</td><td>++</td></tr>
<tr><td>AADT* <200,000</td><td>+</td></tr>
<tr><td colspan="3">*AADT (annual average daily traffic) is defined as average daily traffic on a roadway link for all days of the week during a period of one year, expressed in vehicles per day (VPD).
Strategies expected to provide protection to roadways carrying AADT over 200,000 were ranked as significantly positive, and those carrying AADT fewer than 200,000 were ranked as positive. All strategies protecting transit assets were ranked significantly positive regardless of the magnitude of ridership.</td></tr>
</table>

Table 4-4: Qualitative Assessment Criteria

CRITERIA ID	PROPOSED CRITERIA	RANKING LOGIC	
F6	Ability of strategy to minimize congestion	Strategies were not evaluated by this criterion in this qualitative assessment, and were ranked as ‘TBD’.	
	Social Criteria	**Ordinal Ranking Rationale**	
S1	Ability of strategy to protect homes	Scenario	Rank
		No homes exist in strategy geographic area	NA
		Strategy not intended to protect homes	0
		Homes protected by strategy	+
		Homes harmed by strategy	-
S2	Ability of strategy to protect jobs	Scenario	Rank
		No businesses exist in strategy geographic area	NA
		Strategy not intended to protect businesses	0
		Businesses protected by strategy	+
		Businesses harmed by strategy	-
S3	Ability of strategy to protect amenities (e.g., bike trail on new levee)	Scenario	Rank
		No Amenities exist in strategy geographic area	NA
		Strategy not intended to protect Amenities	0
		Amenities protected by strategy	+
		Amenities harmed by strategy	-
S4	Ability of strategy to protect transit routes in or within ½ mile of communities of concern (CC)	Strategies were not evaluated by this criterion in this qualitative assessment, and were ranked as ‘TBD’. Quantitative evaluation will include changes in transit routes.	
S5	Ability of strategy to minimize vehicle hours of delay for trips in lowest income category (compared to all other income categories)*	Strategies were not evaluated by this criterion in this qualitative assessment, and were ranked as ‘TBD’. Quantitative evaluation will include changes in regional travel.	
	Environmental Criteria	**Ordinal Ranking Rationale**	
E1	Ability of strategy to protect ecosystem value/functions	Scenario	Rank
		No ecosystems exist in strategy geographic area	NA
		Strategy not intended to protect ecosystems	NA
		Ecosystems protected and enhanced by strategy	++
		Ecosystems protected but not enhanced by strategy	+
		Ecosystems harmed by strategy but mitigated elsewhere	0
		Ecosystems harmed by strategy and not mitigated elsewhere	-
		This criterion was not applied to governance and informational strategies.	

Table 4-4: Qualitative Assessment Criteria

<table>
<tr><th>CRITERIA ID</th><th>PROPOSED CRITERIA</th><th colspan="2">RANKING LOGIC</th></tr>
<tr><td>E2</td><td>Ability of strategy to minimize emissions of greenhouse gases and criteria air pollutants</td><td colspan="2">Strategies were not evaluated by this criterion in this qualitative assessment, and were ranked as ‘TBD.’ Quantitative evaluation will include changes in regional travel and emissions.</td></tr>
<tr><td></td><td>Governance-related Criteria</td><td colspan="2">Ordinal Ranking Rationale</td></tr>
<tr><td rowspan="5">A1</td><td rowspan="5">Ability of strategy to leverage potential for jurisdictional collaboration</td><td><u>Scenario</u></td><td><u>Rank</u></td></tr>
<tr><td>Strategy can be implemented by single agency</td><td>-</td></tr>
<tr><td>Strategy can be implemented by single agency in collaboration with other agencies</td><td>0</td></tr>
<tr><td>Strategy requires collaboration of limited agencies with jurisdictional authority</td><td>+</td></tr>
<tr><td>Strategy requires collaboration of numerous agencies with jurisdictional authority</td><td>++</td></tr>
<tr><td>A2</td><td>Ability of strategy to receive funding</td><td colspan="2">Strategies were not evaluated by this criterion in this qualitative assessment, and were ranked as ‘Unknown’</td></tr>
<tr><td rowspan="4">A3</td><td rowspan="4">Ability of strategy to address regulatory or legal issues**</td><td><u>Scenario</u></td><td><u>Rank</u></td></tr>
<tr><td>No regulatory or legal complications</td><td>+</td></tr>
<tr><td>Strategy requires permitting</td><td>-</td></tr>
<tr><td>Strategy requires permitting and California Environmental Quality Act (CEQA) compliance</td><td>--</td></tr>
</table>

* Ultimately this criterion was not used, due to lack of resources to carry out the modelling required.

** While strategies requiring multi-jurisdictional collaboration can be more complex and challenging to implement, one of the priorities in this project was to gain a better understanding of strategies that involve multiple agencies. Given that this project has brought together multiple agencies such as MTC, BCDC, Caltrans, and BART to develop adaptation strategies for transportation assets at a sub-regional scale, strategies with a high potential for jurisdictional collaboration were rated as more favorable than strategies that could be implemented by a single agency.

Figure 4-1: Qualitative Assessment Results for Informational Strategies

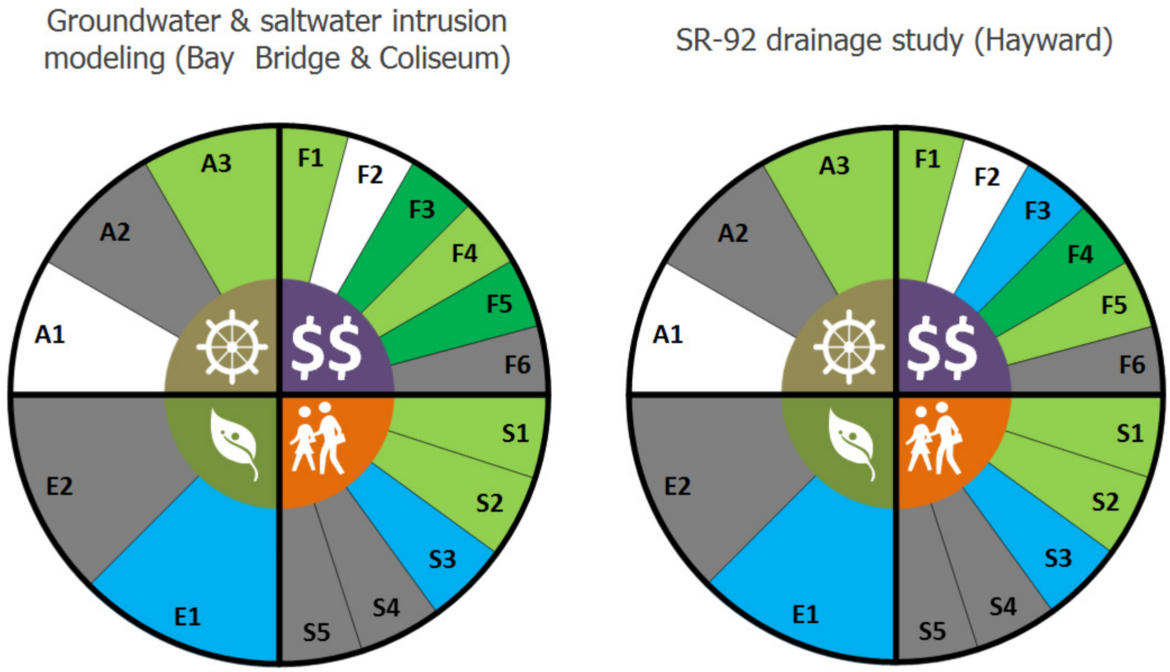


Figure 4-2: Qualitative Assessment Results for Governance Strategies

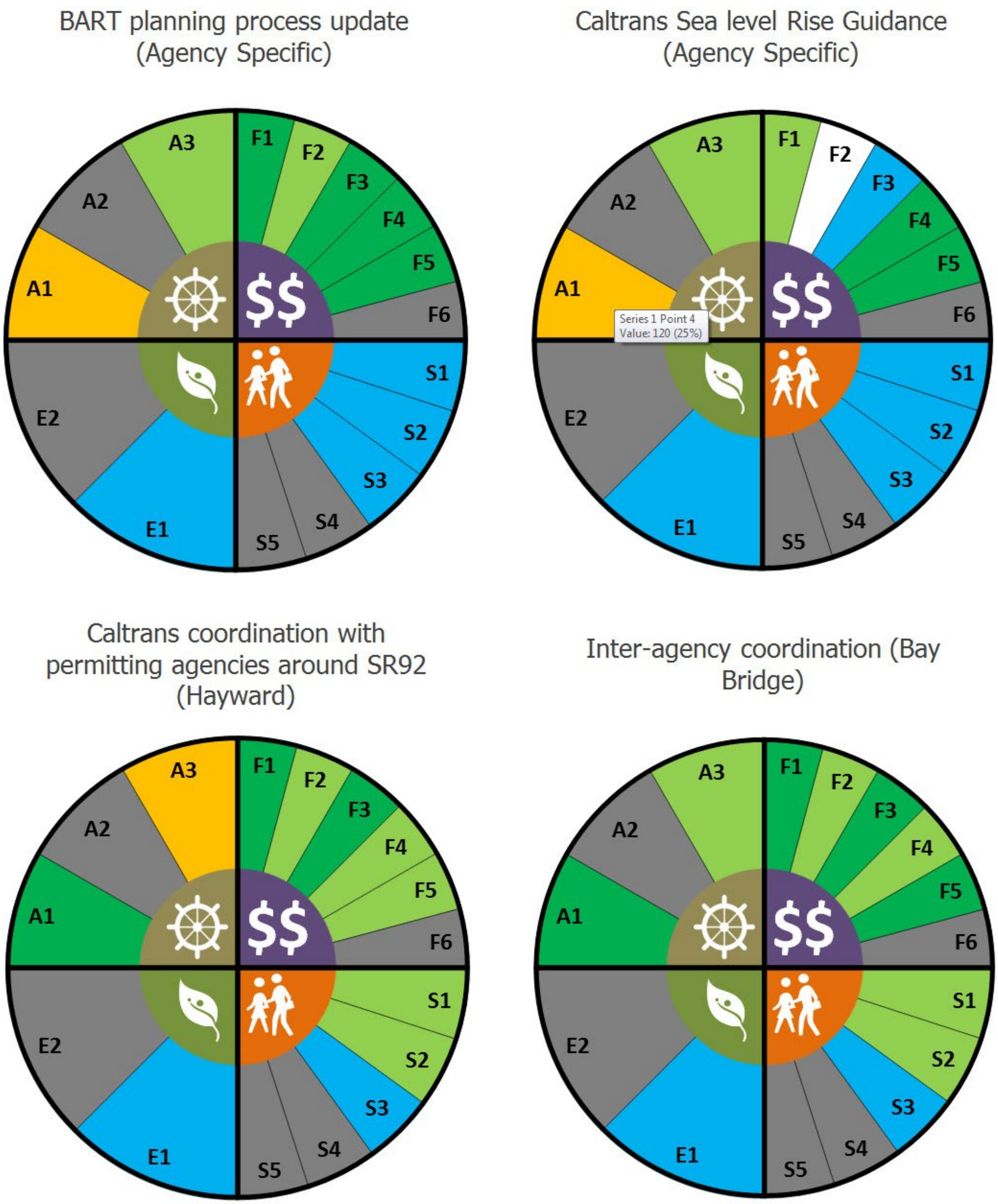


Figure 4-3: Qualitative Assessment Results for Asset-specific Physical Strategies

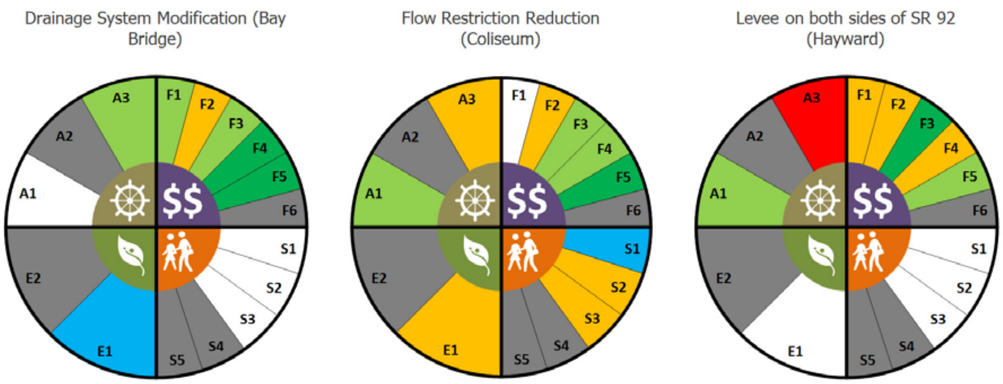
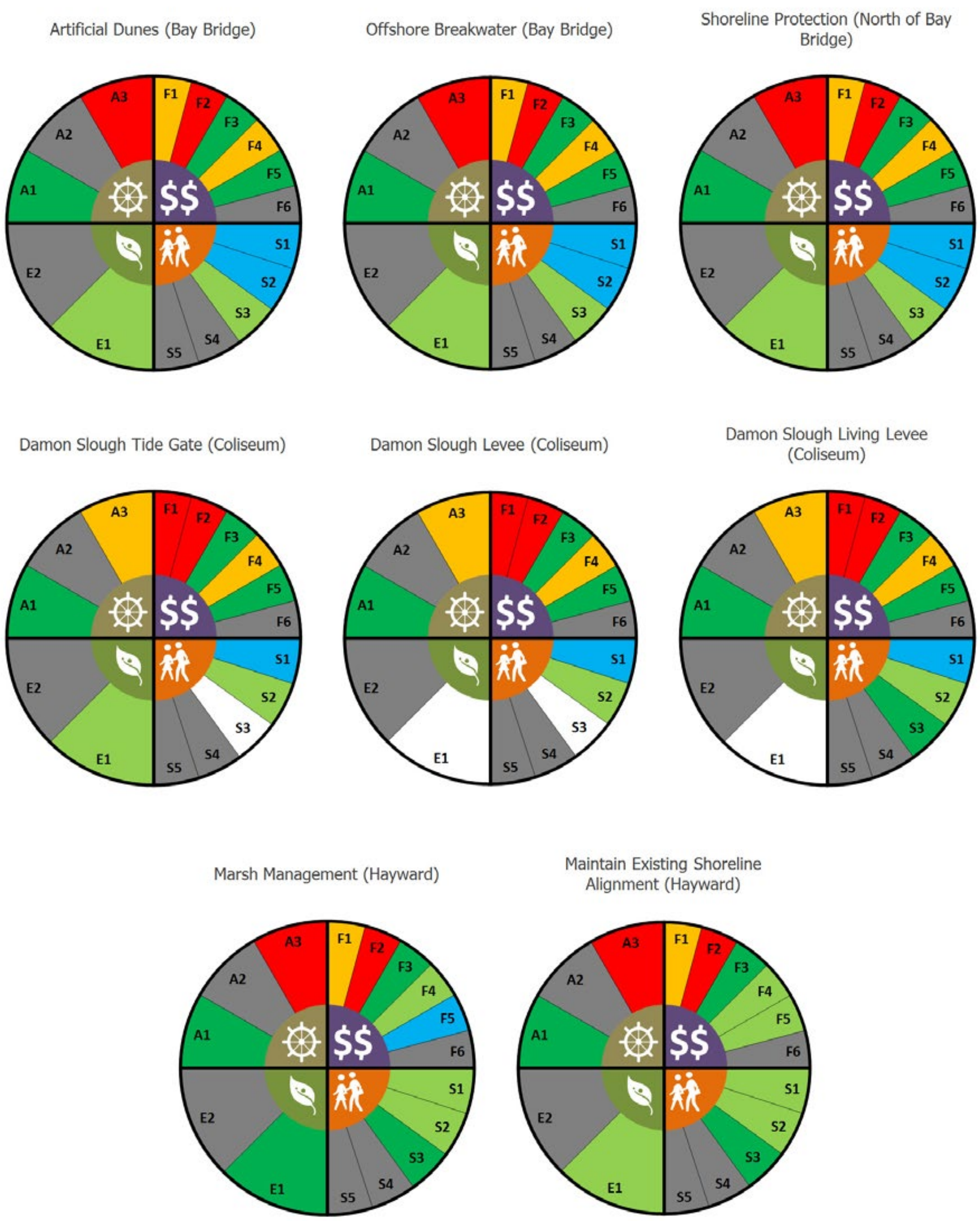


Figure 4-4: Qualitative Assessment Results for Focus area-wide Physical Strategies



- Strategies involving ‘state-of-the-art’ design or innovation should be prioritized for this type of pilot project to test solutions. For example, a living levee is could be considered more innovative than a conventional levee, and should therefore be prioritized for this strategy selection process to result in the greatest increase in knowledge regarding potential adaptation strategies.

Strategy-specific Evaluation Guidelines:

- The vulnerability assessment (see Appendix B) on the focus areas produced by AECOM has highlighted the need for improved knowledge on drainage near SR 92. BCDC communicated the importance of selecting strategies focusing on the Hayward area. This should be taken into account in the strategy selection process.
- Assets in the Bay Bridge Focus Area are also extremely critical, and at least one of the focus area strategies should be for the Bay Bridge Focus Area, as the benefits of protecting these assets are high.

Based on the results of the qualitative assessment, and the supplementary guidelines, a final list of 5 adaptation strategies was selected from the short-listed 17 strategies identified in the screening exercise. The five strategies included at least one strategy for each focus area and at least one strategy for each vulnerability type.

The final strategies selected were:

- Strategies addressing physical and functional vulnerabilities
    - Bay Bridge Focus Area – Artificial dunes[35]
    - Bay Bridge Focus Area – Offshore breakwater
    - Coliseum Focus Area – Damon Slough Living Levee
- Strategies addressing informational vulnerabilities
    - Hayward Focus Area - State Route 92 drainage study
- Strategies addressing governance vulnerabilities
    - BART planning process update (Please note that this strategy was renamed to ‘*Mainstreaming climate change risk in Transportation Agencies’* in order to expand its relevance clearly beyond BART.

4.4 BASELINE ‘NO-ACTION’ SCENARIOS

This section describes the purpose and evaluation methodology of the focus area baseline coastal flooding scenarios. The baseline coastal flooding scenarios for each of the focus areas are:

- Bay Bridge Touchdown Focus Area – MHHW+36 inches of sea level rise;
- Coliseum Focus Area – MHHW+48 inches of sea level rise; and
- Hayward Focus Area – MHHW+48 inches of sea level rise.

The baseline scenario for each focus area was determined based on the minimum level of inundation that would first affect key transportation assets in the focus area, and cause disruption to these assets.

[35] Note that although an artificial dune was first identified as a potential strategy to pair with the breakwater, after initial analysis, a living levee was identified as more appropriate for this location.

4.4.1 PURPOSE AND EVALUATION METHODOLOGY

The purpose of developing a future baseline coastal flooding scenario for each of the three focus areas was to understand the adverse financial, environmental, and social impacts of no action (i.e. conditions under which no adaptation strategies are implemented to protect assets in the focus areas from sea level rise and storm events). The results of the strategies were therefore assessed against these scenarios. Some of the evaluation criteria which were used in the qualitative assessment of the adaptation strategies were also used in the evaluation of adverse impacts under the baseline scenario for each focus area. Table 4-5 explains if and how the criteria were used in the evaluation of adverse impacts under the baseline scenarios.

For the evaluation criteria which required the use of MTC's regional travel demand model, the following methodology and assumptions were used:

- Only trips taking place within the MTC regional travel model were counted. This means that trips in/out of the nine county Bay Area model were not included in the results, as the majority of trips are typically within the nine county Bay Area. This is not expected to have a significant impact on comparing scenario results.
- Only the trip assignment step was run in the model. The preceding steps of trip generation, trip distribution, and mode choice were not re-run, as doing so would have been too resource intensive for the illustrative purposes of this exercise. This means that the number of trips generated by zone, trip distributions between origins and destinations, and mode choices were all held constant, and only the route assignment (from origin to destination) was changed. This assumption illustrates the anticipated total number of impacted trips, but does not account for behavioral adaptation among commuters (e.g., commuters may choose not to travel at all, or may choose a different mode of transportation if their preferred mode is not available).
- Trips were removed from Transport Analysis Zones (TAZs) that were fully inundated.
- In the baseline scenario for the Coliseum Focus Area, approximately 200,000 trips were removed to account for the large land area inundated under this scenario. This means that it was assumed that no trips would occur to and from the inundated areas. One-half of the trips were assumed to be reallocated elsewhere. This amounted to approximately 40,000 trips.

4.4.2 FOCUS AREA BASELINE SCENARIOS

This section describes the baseline coastal flooding scenario for each focus area. The baseline scenario for each focus area was developed under the assumption that current shoreline defenses are maintained at their existing level and no additional defenses or adaptation strategies are put in place. The baseline scenarios also assumed that the asset managers, such as Caltrans and BART, will have sufficient time to institute operational preparedness measures to protect critical assets and minimize the damage associated with temporary flooding (e.g. sand bagging, placement of temporary flood proofing measures, temporary station closures).

Table 4-5: Baseline Scenario Evaluation Criteria

CRITERIA ID	EVALUATION CRITERIA	ROLE IN EVALUATION OF ADVERSE IMPACTS UNDER THE BASELINE SCENARIO
Financial Criteria		
1	Impacts on costs (cost of repairing core assets and adjacent assets (where data is available) due to partial damage caused by coastal flooding) Note: this criterion is a modified version of the criterion used in the qualitative assessment.	This criterion was used in the evaluation of adverse impacts under the baseline scenarios For the baseline scenario, the cost of partial damage was estimated through a number of methods 1. Case study research – similar storm event that impacted similar assets within the Caltrans service area were identified, and their findings were extrapolated to this project. 2. Assumptions for costs of emergency preparedness measures based on measures employed under similar circumstances. Specifically, staff time required for monitoring, patrol, and placement of road closure signs was included in estimating the cost of preparedness.
2	Annual operating and maintenance costs of adaptation strategy	This criterion was not used in the evaluation of adverse impacts under the baseline scenarios.
3	Duration / life span of strategy	This criterion was not used in the evaluation of adverse impacts under the baseline scenarios.
4	Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes	This criterion was not used in the evaluation of adverse impacts under the baseline scenarios.
5	Impacts on mobility due to operational disruptions (applicable to transit systems and roadway systems) • *Transit Systems (BART)* impacts - measured via ridership • *Roadway Systems* impacts – measured via vehicle miles traveled (VMT),vehicle hours traveled (VHT) for passenger vehicles and trucks	This criterion was used in the evaluation of adverse impacts on transit systems and roadway systems under the baseline scenarios. • Transit Systems (BART): BART's average monthly boarding data were used to evaluate the number of passenger boardings affected by station and track under the baseline scenarios. • Roadway Systems: MTC's regional travel demand model was used in this analysis. The regional travel activity (measured by VMT and VHT) was summarized after removing links expected to fail or be disrupted under the baseline scenarios. The regional results illustrated that disruption to critical assets can impact other parts of the roadway system.
6	Impacts on mobility due to increase in congestion (only applicable to roadway systems) • *Roadway Systems Impacts* – measured via vehicle hours of delay (VHD)	This criterion was used in the evaluation of adverse impacts on roadway systems under the baseline scenarios. Roadway Systems: MTC's regional travel demand model was used in this analysis. The vehicle hours of delay were summarized for both passenger vehicles and heavy trucks after removing links disrupted under the baseline scenarios.
Social Criteria		
7	Impacts on population	This criterion was used in the evaluation of adverse impacts under the baseline scenarios. Projected population data for the year 2040 from Plan Bay Area were used in this analysis. Under the baseline scenario, the population expected to be impacted by inundation and flooding were quantified based on the results of the inundation mapping analysis (described in Chapter 3).

Table 4-5: Baseline Scenario Evaluation Criteria

CRITERIA ID	EVALUATION CRITERIA	ROLE IN EVALUATION OF ADVERSE IMPACTS UNDER THE BASELINE SCENARIO
8	Impacts on jobs	This criterion was used in the evaluation of adverse impacts under the baseline scenarios. Projected employment data for the year 2040 from Plan Bay Area were used in this analysis. Under the baseline scenario, the number of jobs expected to be impacted by inundation and flooding were quantified based on the results of the inundation mapping analysis (described in Chapter 3).
9	Impacts on amenities (e.g., bike trail on new levee)	This criterion was not used in the evaluation of adverse impacts under the baseline scenarios.
10	Impacts on # of transit routes in or within ½ mile of communities of concern (CC)	This criterion was used in the evaluation of adverse impacts under the baseline scenarios. The number of transit routes disrupted under the baseline scenario was identified using the results of the inundation mapping analysis and GIS resources on transit routes.
11	Impacts on vehicle hours of delay for trips in lowest income category (compared to all other income categories):	The original methodology proposed summarizing the MTC regional travel demand model data by income category. However, this is a more complex process then initially conceived and due to lack of resources it was agreed to remove this criteria from the process.
Environmental Criteria		
11	Impacts on wetlands/habitat	GIS data from the San Francisco Estuary Institute (SFEI) was used in this analysis. Under the baseline scenario, the acres of wetlands expected to be impacted by inundation and flooding were quantified based on the results of the inundation mapping analysis (described in Chapter 3).[36]
12	Impacts on emissions • GHG emissions – as a direct function of automobile vehicle miles traveled (VMT) • Criteria Air Pollutants – as a direct function of automobile vehicle miles traveled (VMT)	This criterion was used in the evaluation of adverse impacts under the baseline scenarios. The EMFAC model was used in this analysis. Region-wide greenhouse gas and criteria air pollutant emissions were estimated using travel model scenario outputs (derived in Criterion #5).
Governance-related Criteria		
13	Potential for jurisdictional collaboration	This criterion was not used in the evaluation of adverse impacts under the baseline scenarios.
14	Funding availability	This criterion was not used in the evaluation of adverse impacts under the baseline scenarios.
15	Significant regulatory or legal issues	This criterion was not used in the evaluation of adverse impacts under the baseline scenarios.

[36] It should be noted that this is a high level analysis based on static inundation maps, and does not account for the dynamic nature of wetlands and habitat, which can help them keep up with permanent inundation or temporary flooding to some extent (though likely not end-of-century MHHW+SLR water elevations). For a more detailed analysis on impacts to wetlands and habitat, marsh sustainability models such as those used by Point Blue (see: www.pointblue.org) are more appropriate, as they have the ability to project the gradual progression of wetlands and habitat from downshifting to permanent inundation.

Table 4-6: Trips removed from Coliseum Focus Area TAZs fully inundated in sea level rise scenario

TIME PERIOD	OAK DAILY TRIPS	OTHER AREAS
Early	3,362	4,582
AM	14,753	28,624
Mid-Day	23,268	41,270
PM	18,342	35,851
Evening	18,871	27,913
Daily	*78,596*	*138,240*

Source: Metropolitan Transportation Commission Travel Demand Model, 2014.

4.4.2.1 BASELINE SCENARIO FOR BAY BRIDGE FOCUS AREA

The baseline scenario that was selected for the Bay Bridge Focus Area is the 36-inch scenario (See Figure 4-5). This level of inundation could occur today under a 50-year storm surge event and is below the FEMA 100-year base flood elevation. The 36-inch scenario can represent the following combinations of mean higher high water levels (MHHW) and sea level rise (SLR):

- MHHW + 36-inch SLR
- MHHW + 24-inch SLR + 1-Year Tide
- MHHW + 18-inch SLR + 2-Year Tide
- MHHW + 12-inch SLR + 10-Year Tide
- MHHW + 6-inch + 25-Year Tide
- MHHW + 0-inch + 50-Year Tide

This baseline scenario results in inundation across the west-bound lanes of the Bay Bridge in the touchdown area. Caltrans provided input into the length of disruption that would occur; along with the temporary procedures they would implement to minimize flood damage. Caltrans reviewed the available procedures to ensure that the assumptions used in the baseline scenario were reasonable. It was assumed that even if flood mitigation measures such as sandbagging are implemented, traffic on roadways proximate to those sandbags would not be flowing because of safety concerns (i.e., agencies will shut these facilities down, temporarily). For the purpose of modeling the baseline scenario, roadway links in the inundation zone were assumed to be completely disabled in the model even if emergency measures implemented by agencies have the ability stave off more significant damage.

The roadway segments that would be disrupted in this focus area under the baseline scenario were identified, and are listed in Table 4-7.

Using the evaluation methodology described in Section 4.4.1, and the information on the assets expected to be disrupted under the baseline scenario, the financial, environmental, and economic impacts under the baseline scenario were evaluated for this focus area, and are shown in Table 4-8. Please note that baseline trips that utilize the Bay Bridge (prior to disruption) do so because it comprises part of the shortest path journey from origin to destination. When this path is disrupted, some portion of trips reroute to less efficient trip paths, thus adding VMT to the regional baseline. Note that, because the method used focuses only on the assignment procedure, not the mode split, diversion to other modes or trip generation is not accounted for in this analysis.

Figure 4-5: Expected inundation of the focus area with 36 inches of SLR (MHHW + 36 inches)

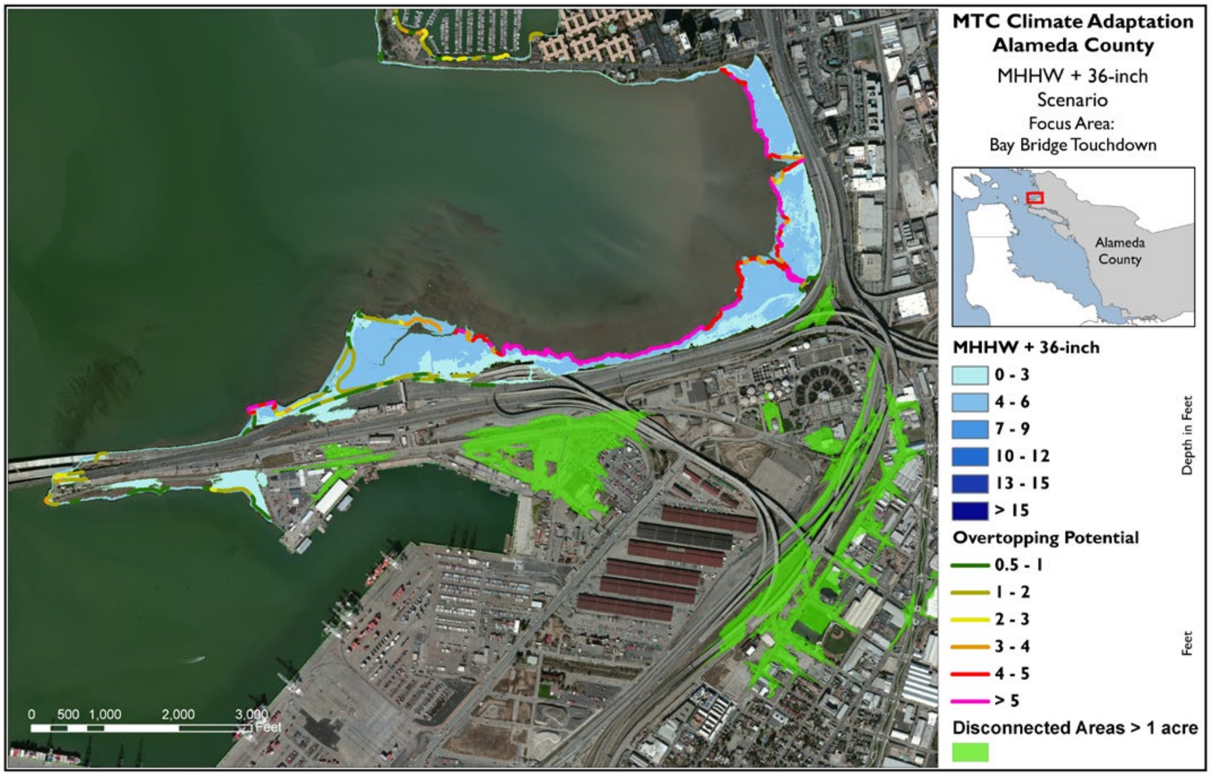


Table 4-7: Roadway segments distributed in Bay Bridge Focus Area

ROUTE	FROM	TO	DISRUPTED
I-80 WB	Beginning of bridge	Toll plaza	2 of 4 lanes

Table 4-8: Adverse Impacts under Bay Bridge Focus Area Baseline Scenario

FINANCIAL IMPACTS	
Daily Cost of repairs to partially damaged assets (in staff time)	Approximately 10 Caltrans Employees[37]
Change in transit ridership (BART)	None
Change in regional vehicle miles traveled (passenger vehicles)	+4,102,540 (+3%)
Change in regional vehicle miles traveled (trucks)	+439,014 (+3%)
Change in regional vehicle hours traveled (passenger vehicles)	+214,888 (+6%)
Change in regional vehicle hours traveled (trucks)	+20,834 (+6%)
Change in regional vehicle hours of delay (passenger vehicles)	+136,830 (+40%)
Change in regional vehicle hours of delay (trucks)	+12,613 (+48%)
SOCIAL IMPACTS	
Population impacted	+5,842 (+100%)
Number of jobs impacted	+971 (+100%)

[37] This estimate was based on feedback from Caltrans staff about the staff time and resources needed to implement the closure of highway lanes during flooding events. The estimate was based on the closure of the ramp connecting Highway 1 to Highway 101 in Marin County. An assumption of 5 employees per highway lane closure was used for this estimate.

Table 4-8: Adverse Impacts under Bay Bridge Focus Area Baseline Scenario

Number of # of transit routes impacted in or within ½ mile of communities of concern (AC Transit local routes)	1
Number of # of transit routes impacted in or within ½ mile of communities of concern (AC Transit tTransbay routes)	27
ENVIRONMENTAL IMPACTS	
Acres of wetlands/habitat impacted	112 acres (+100%)[38]
Change in GHG emissions from all on-road vehicles (tons per day)	113,532 (+3.0%)
Change in Criteria Air Pollutant emissions (tons per day)	See below
ROG	+31.0 (+2.6%)
NOx (Summertime)	+49.0 (+2.4%)
CO	+248.0 (+2.9%)
PM_{10}	+42.0 (+2.6%)
$PM_{2.5}$	+10.2 (+2.7%)
NOx (Wintertime)	+54.2 (+2.5%)

4.4.2.2 BASELINE SCENARIO FOR COLISEUM FOCUS AREA

The baseline scenario that was selected for the Oakland Coliseum Focus Area is the 48-inch scenario. This level of inundation is greater than would occur today under a 100-year storm surge event (i.e. this would be comparable with a 42-inch scenario, which was not mapped in this analysis). This level of inundation is also similar to that which occurs with 24-inch of sea level rise, a 10-year storm surge event, and a 10-year riverine flood event. Additional combinations of mean higher high water levels (MHHW) and sea level rise (SLR) represented by the 48-inch scenario are:

- MHHW + 48-inch SLR
- MHHW + 36-inch SLR + 1-Year Tide
- MHHW + 30-inch SLR + 2-Year Tide
- MHHW + 24-inch SLR + 10-Year Tide
- MHHW + 18-inch + 25-Year Tide
- MHHW + 12-inch + 50-Year Tide
- MHHW + 0-inch + 100-Year Tide

It was found this inundation scenario results in the first direct impacts to I-880, the BART station, Amtrak station, and other assets. Although the BART station would temporarily close when the area is flooded, the BART system would remain operational (i.e. BART trains would not stop at this station, but would continue running), but system-wide delays would still likely occur. Caltrans and BART provided input into the length of disruption that would occur; along with the temporary procedures they would implement to minimize flood damage to their respective assets. BART conducted research on past efforts to resume services when other stations have had shut downs to determine how quickly a BART station could be operable again, and shared this with the Consultant Team. For example, BART shared data on hours of delay caused by a flooding event at the Powell Street BART station in San Francisco on February 28th, 2014, which flooded the control room and resulted in system-wide delays, but did not cause the station to shut down.

The roadway segments that would be disrupted in this focus area under the baseline scenario were identified, and are in Table 4-9:

38 This estimate represents the worst-case scenario, under which the acres of wetlands and habitat will be permanently inundated. It does not taken into account the ability of wetlands and habitat to keep up with lower magnitudes of sea level rise, or adapt to temporary flooding.

Table 4-9: Roadway segments distributed in Coliseum Focus Area

ROUTE	FROM	TO	DISRUPTED
I-880 SB	54^{th} Ave	Hegenberger Rd	2 of 4 lanes
I-880 NB	54^{th} Ave	Hegenberger Rd	2 of 4 lanes
I-880 NB/SB	7^{th} Street	Grand Avenue	8 lanes
San Leandro Street (Lion Creek)	66^{th} Street	69^{th} Street	7 lanes
San Leandro Street	50^{th} Ave	54^{th} Ave	4 lanes
Hegenberger Road (San Leandro Creek)	San Leandro Street	I-880	4 lanes
98^{th} Avenue NB/SB	Airport Drive	Airport Access Rd	2 lanes
Doolittle Drive	Bessie Coleman	Harbor Bay Pkwy	2 lanes
Ron Cowan Pkwy	Bessie Coleman	NA	4 lanes
Airport Drive NB/SB	Doolittle Drive	Airport	4 lanes
Capitol Corridor/Amtrak / Union Pacific Freight*	66^{th} Street	Hegenberger Rd	All tracks
BART station	Na	Na	Station

**Note that freight impacts are not included in this analysis*

Using the evaluation methodology described in Section 4.4.1, and the information on the assets expected to be disrupted under the baseline scenario, the financial, environmental, and economic impacts under the baseline scenario were evaluated for this focus area, and are shown in Table 4-10.

4.4.2.3 BASELINE SCENARIO FOR HAYWARD FOCUS AREA

The baseline scenario that was selected for the Hayward Focus Area is the 48-inch scenario. This scenario results in inundation along the westbound lanes of SR 92 near the bridge touchdown area. This level of inundation is greater than would occur today under a 100-year storm surge event. Additional combinations of mean higher high water levels (MHHW) and sea level rise (SLR) represented by the 48-inch scenario are:

- MHHW + 48-inch SLR
- MHHW + 36-inch SLR + 1-Year Tide
- MHHW + 30-inch SLR + 2-Year Tide
- MHHW + 24-inch SLR + 10-Year Tide
- MHHW + 18-inch + 25-Year Tide
- MHHW + 12-inch + 50Year Tide
- MHHW + 0-inch + 100Year Tide

Caltrans provided input into the length of disruption that would occur during events of a similar nature; along with the temporary procedures they would implement to minimize flood damage.

The roadway segments that would be disrupted in this focus area under the baseline scenario were identified, and are listed below:

Table 4-10: Adverse Impacts under Coliseum Focus Area Baseline Scenario

FINANCIAL IMPACTS	
Daily Cost of repairs to partially damaged assets (in staff time)	Approximately 90 Caltrans employees[39]
Change in transit ridership (BART average weekday boardings disrupted from damage to station access)	-7,100 (-100%)
Change in transit ridership (BART average weekday system-wide boardings disrupted from damage to traction power and station access)	- 84,842 (-100%)
Change in regional vehicle miles traveled (passenger vehicles)	+216,670 (+0.15%)
Change in regional vehicle miles traveled (trucks)	-9,221 (-0.06%)
Change in regional vehicle hours traveled (passenger vehicles)	+31,303 (+1%)
Change in regional vehicle hours traveled (trucks)	+3,160 (+1%)
Change in regional vehicle hours of delay (passenger vehicles)	+22,484 (+7%)
Change in regional vehicle hours of delay (trucks)	+2,167 (+8%)
SOCIAL IMPACTS	
Population impacted	8,670
Number of jobs impacted	4,730
Number of # of transit routes impacted in or within ½ mile of communities of concern (AC Transit local routes)	9
Number of # of transit routes impacted in or within ½ mile of communities of concern (AC Transit Transbay routes)	2
ENVIRONMENTAL IMPACTS	
Acres of wetlands/habitat impacted	1,103 acres (+100%)
Change in GHG emissions from all on-road vehicles (tons per day)	110,558 (+0.3%)
Change in Criteria Air Pollutant emissions (tons per day)	
ROG	30.3 (+0.22%)
NOx (Summertime)	-47.8 (-0.06%)
CO	241.7 (+0.32%)
PM_{10}	41.1 (+0.26%)
$PM_{2.5}$	9.9 (+0.23%)
NOx (Wintertime)	-52.9 (-0.03%)

Table 4-11: Roadway segments distributed in Hayward Focus Area

ROUTE	FROM	TO	DISRUPTED
SR 92 W	Toll Plaza	Johnson Rd Footbridge	3 of 5 lanes
SR 92 E	Toll Plaza	NA	2 of 3 lanes
Eden Landing Road	Arden Road	Investment Blvd	2 lanes
Arden Road	Eden Landing Rd	Rail ROW / Industrial Blvd	2 lanes

Using the evaluation methodology described in Section 4.4.1, and the information on the assets expected to be disrupted under the baseline scenario, the financial, environmental, and economic impacts under the baseline scenario were evaluated for this focus area, and are shown in Table 4-12.

39 This estimate was based on feedback from Caltrans staff about the staff time and resources needed to implement the closure of highway onramps as well as local road segment closures during flooding events. The estimate was based on the closure of the ramp connecting Highway 1 to Highway 101 in Marin County. An assumption of 5 employees per highway lane closure and 2.5 employees per local road segment closure was used for this estimate.

Table 4-12: Adverse Impacts under Hayward Focus Area Baseline Scenario

FINANCIAL IMPACTS	
Cost of repairs to partially damaged assets (in staff time)	35[40]
Change in transit ridership (BART)	None
Change in regional vehicle miles traveled (passenger vehicles)	+1,525,678 (+1%)
Change in regional vehicle miles traveled (trucks)	+131,907 (+1%)
Change in regional vehicle hours traveled (passenger vehicles)	+81,616 (+2%)
Change in regional vehicle hours traveled (trucks)	+7,461 (+2%)
Change in regional vehicle hours of delay (passenger vehicles)	+51,462 (+15%)
Change in regional vehicle hours of delay (trucks)	+4,952 (+15%)
SOCIAL IMPACTS	
Population Impacted	None
Number of jobs impacted	994
Number of transit routes impacted in or within ½ mile of communities of concern (AC Transit local routes)	1
Number of transit routes impacted in or within ½ mile of communities of concern (AC Transit transbay routes)	1
ENVIRONMENTAL IMPACTS	
Acres of wetlands/habitat impacted	1,506 acres (+100%)
Change in GHG emissions from all on-road vehicles (tons per day)	+111,509 (+1.1%)
Change in Criteria Air Pollutant emissions (tons per day)	See below
ROG	+30.6 (+1.0%)
NOx (Summertime)	+48.2 (+0.8%)
CO	+243.7 (+1.2%)
PM_{10}	+41.4 (+1.1%)
$PM_{2.5}$	+10.0 (+1.1%)
NOx (Wintertime)	+53.4 (+0.9%)

40 This estimate was based on feedback from Caltrans staff about the staff time and resources needed to implement the closure of highway lanes during flooding events. The estimate was based on the closure of the ramp connecting Highway 1 to Highway 101 in Marin County. An assumption of 5 employees per highway lane closure and 2.5 employees per local road segment closure was used for this estimate.

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Adaptation Strategy: Bay Bridge Touchdown Living Levee and Breakwater

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5. ADAPTATION STRATEGY: BAY BRIDGE TOUCHDOWN LIVING LEVEE AND BREAKWATER

This section presents details of two adaptation strategies that have been proposed for the Bay Bridge Focus Area: the installation of a living levee immediately north of I-80 at the San Francisco-Oakland Bay Bridge touchdown (Bay Bridge touchdown), and the installation of a breakwater offshore of Radio Beach. The living levee will protect against future inundation and flooding due to sea level rise (SLR) and storm surge. The breakwater will reduce wave heights and protect the area from future wave overtopping and wave-induced erosion. The living levee, in combination with the breakwater, is conceptually designed to protect the tool plaza area against at least a mid-century sea level rise magnitude (e.g., approximately 12 inches of SLR) coupled with a 100-year extreme tide event. The design includes freeboard to meet the requirements for FEMA accreditation, protect against wave overtopping, and be adaptable to accommodate higher SLR magnitudes (e.g., 36 inches). It is important to note, however, that a broader suite of strategies to address other vulnerabilities identified in the focus area will be necessary in tandem with these strategies to holistically protect the function of the Bay Bridge and adjacent assets.

Following the completion of detailed inundation mapping, several adaptation strategies were considered, which, when implemented, would protect highly vulnerable sections of I-80 and the toll plaza, as well as Radio Beach, the marsh complex, and the radio towers and associated facilities from future inundation and flooding. This section explores the feasibility of building a living levee near the partially-paved maintenance road that sits adjacent to the north side of I-80 at a low elevation. This strategy is designed to address the key shoreline locations that would cause flooding of the toll plaza and interstate west-bound travel lanes. Initial analysis suggested that an artificial dune alone might not adequately protect the area from SLR and storm surge and therefore, AECOM has designed a conceptual living levee structure instead. This section also explores the feasibility of installing a breakwater offshore of Radio Beach to reduce wave runup and overtopping that may accompany future SLR. Previous analyses that have been conducted for this focus area under the Adapting to Rising Tides project[41] did not include wave physics or any changes in wave characteristics that may occur as a result of SLR. It is anticipated that overtopping and wave-induced erosion will generally increase with SLR simply as a function of higher total water levels (TWL), and the installation of a breakwater will help protect the shoreline from these impacts. The full list of adaptation strategies developed in the in the initial stages of this study (see Compendium of Strategies in Appendix C for more information) should be reviewed prior to the implementation of either of these two proposed strategies.

The following sections provide a description of the Bay Bridge touchdown focus area (Section 5.1), a description of preliminary coastal engineering analysis and the development of design criteria for both proposed strategies (Section 5.2), conceptual designs (Section 5.3), partners (Section 5.4), implementation steps (Section 5.5), operations and maintenance considerations (Section 5.6), and regulatory considerations (Section 5.7). In addition, the impacts of the two strategies on the environment, equity, and mobility are discussed in Section 5.8. A planning level estimation of design and implementation costs is presented in Section 5.9. Finally conclusions and recommendations for further research are discussed in Section 5.10.

[41] http://www.mtc.ca.gov/planning/climate/RisingTides-TechnicalReport.pdf

5.1 FOCUS AREA DESCRIPTION

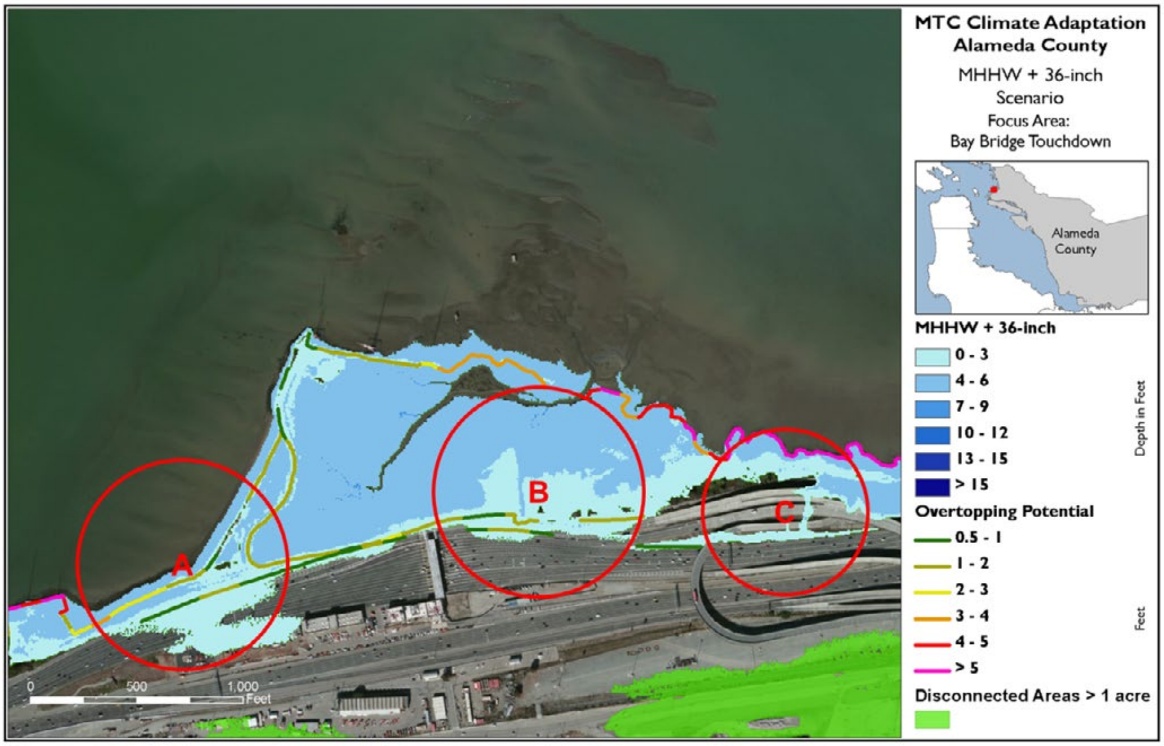
The Bay Bridge touchdown focus area is located south of Emeryville in San Francisco Bay, along the northern boundary of the Oakland Outer Harbor (Figure 5-1). The area includes the Bay Bridge touchdown and westbound portion of the toll plaza as well as the intersection of interstate highways I-580, I-80, and I-880. The area immediately north of the Bay Bridge touchdown is the Emeryville Crescent tidal wetland, which experiences regular tidal inundation under existing conditions. This area also includes Radio Beach, which is a strip of unimproved shoreline bordering the most northerly access ramp to westbound I-80 and the Bay Bridge. There are three radio towers near the north end of Radio Beach. Access to the towers is gained through several elevated dirt roads throughout the wetland.

Figure 5-1: Location of the focus area at the Bay Bridge Touchdown in San Francisco Bay (left). Close-up of the focus area and assets including Radio Beach, I-80, and the toll plaza facilities (right)

Many stakeholders have active interests in this focus area. These include Caltrans, which is responsible for the operations and maintenance of the state highways and toll bridges, the San Francisco Bay Conservation and Development Commission (BCDC), the Metropolitan Transportation Commission (MTC), and the Bay Area Toll Authority (BATA), which is the transportation planning and financing agency in the region. Both BCDC and MTC are coordinating conservation, planning, and development efforts in the study area. In addition, the Gateway Park Working Group (GPWG), which consists of several agencies, including those already listed as well as others such as the East Bay Municipal Utility District (EBMUD), East Bay Regional Parks District (EBRPD) and the City of Oakland, is developing a Master Plan for rehabilitation of part the area on the opposite side of I-80 (including Radio Beach) at the bridge approach for recreation and public access (GPWG 2012). Finally, the Port of Oakland owns and maintains the dirt access roads and radio towers and manages an active maintenance maritime port directly south of the focus area.

This area is expected to be permanently inundated by 36 inches of SLR (BCDC 2011; AECOM 2014). Permanent *inundation* occurs when an area is exposed to regular daily tidal inundation. A permanently inundated area can no longer be used in the same way as an inland area due to the frequency of its exposure to sea water. At 36 inches of SLR, the westbound lanes of the I-80 approach will be permanently inundated at three distinct sites: a low-lying section of the highway southwest of Radio Beach, a site immediately east of the toll plaza, and a site below the West Grand Avenue on-ramp (labeled A, B, and C respectively in Figure 5-2).

Figure 5-2: Expected inundation of the focus area with 36 inches of SLR (MHHW + 36 inches), which is equivalent to 9.2 ft. NAVD88. Inundation of the west bound lanes is anticipated to occur at three distinct sites (labeled A, B, and C)



In addition to assessing permanent inundation, AECOM (2014) also assessed the effects of temporary flooding from extreme tide events. Temporary *flooding* occurs when an area is exposed to episodic, short duration, extreme tide events of greater magnitude than normal tide levels. Inland areas may be temporarily flooded during an extreme tidal event while maintaining at least a portion of their functionality once the floodwaters recede. However, sensitive assets may suffer irreversible damage if exposed to any amount of water, even temporarily. It should be noted that AECOM's assessment of extreme tide events accounted for storm surge, and therefore represented the still water level (SWL), but did not account for wave effects. This analysis indicated that the same aforementioned sites (A, B and C) would also be vulnerable to flooding under the following combined scenarios of SLR and extreme tide events (all of which are approximately equivalent to a water level of 9.2 feet NAVD88[42]):

- 24 inches of SLR coupled with a 1-year tide event
- 18 inches of SLR coupled with a 2-year tide event
- 12 inches of SLR coupled with a 5-year tide event
- Existing conditions coupled with a 50-year tide event

Further details on the inundation and flooding analysis are presented in the Bay Bridge Focus Area Technical Memorandum (2014) (see Appendix B).

[42] North American Vertical Datum of 1988. NAVD88 is a vertical control datum of orthometric height established in 1988. It is widely used in land surveying.

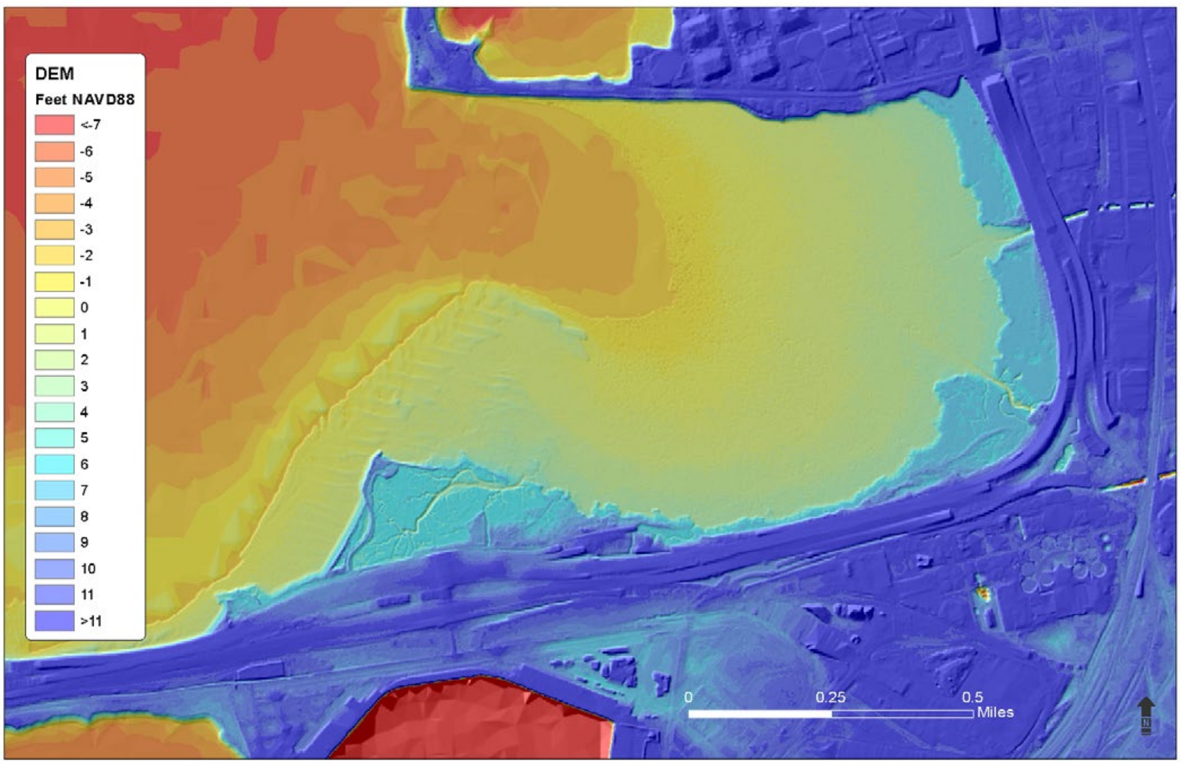
5.2 DEVELOPMENT OF DESIGN CRITERIA

Several data sets were leveraged for this study to develop design criteria for the living levee and breakwater. The bathymetric and topographic data (Section 5.2.1), tide data and SLR scenarios (Section 5.2.2), and wave data (Section 5.2.3) are described in the following sections.

5.2.1 BATHYMETRIC AND TOPOGRAPHIC DATA

Bathymetric and topographic data were used to determine elevations at each site in the focus area and develop the conceptual designs. AECOM leveraged a merged bathymetric/topographic Digital Elevation Model (DEM) with 5 ft.-horizontal resolution for this study (Figure 5-3). The topographic portion of the DEM was built from airborne topographic light detection and ranging (LiDAR) data collected and processed by the United States Geological Survey (USGS) in 2010. The bathymetric portion of the DEM was built from hydrographic sonar data collected and processed by the California Seafloor Mapping Project (CSMP) from 2004-2009. The DEM was projected horizontally in California State Plane III coordinates, referenced to the North American Datum of 1983 (NAD1983) and vertically in NAVD88. The DEM was initially developed for the Federal Emergency Management Agency (FEMA) San Francisco Bay Area Coastal Study [43] (BakerAECOM 2013).

Figure 5-3: Image of the 5 ft. horizontal resolution DEM of the focus area



5.2.2 TIDE AND SEA LEVEL RISE DATA AND ANALYSIS

Consideration of future sea level rise and extreme tide levels were used in the conceptual design of both the living levee and the breakwater. To determine the overall height of the structures a range of still water levels (SWL) were considered, including current, mid-century (e.g., 12 inches of sea level rise), and end-of-century (36 inches of sea level rise), in addition to 100-year SWL. The current estimate of the 100-year

[43] www.r9coastal.org

SWL used in the conceptual design was 9.8 feet NAVD88 (BakerAECOM 2013). SWL includes the effects of tides and storm surge, but does not account for local variations in water levels that may occur due to waves and wave setup; therefore the 100-year wave-driven total water levels (TWL) were also considered (10.7 feet NAVD88, BakerAECOM2013).

The current MHHW water level (assuming no SLR) was also used in the conceptual design process. Current MHHW was derived from the MIKE21 model output (DHI 2011). The MHHW tidal datum was calculated using the portion of the model output time series corresponding to the most recent National Tidal Datum Epoch (1983 through 2001), which is a specific 19-year period adopted by National Oceanic and Atmospheric Administration (NOAA) to compute tidal datums. The current MHHW water level for this area was determined to be at 6.2 feet NAVD88.

This MHHW elevation matches the MHHW elevation for the proximate Berkeley tide gage (37.8650° N, 122.3070° W). Data from the Berkeley tide gage is presented in Table 5-1, as it may inform the development of other strategies, including the offshore breakwater. Specifically, the tide gage data can be used to develop detailed designs, cost estimation, and construction plans for the breakwater.

Table 5-1: Berkeley Tide Gage Station (9414816) Datum Elevations

DATUM	ELEVATION (FT. NAVD88)
MHHW	6.2
MHW	5.6
MSL	3.4
MLW	1.3
MLLW	0.1
NAVD88	0.00

Source: http://www.csc.noaa.gov/

The magnitude of sea level rise that would cause permanent inundation in the area was determined via inundation mapping analysis. As described previously, sites along I-80 in the Bay Bridge Focus Area are expected to be inundated at MHHW with a minimum of 36 inches (3 feet) of SLR (AECOM 2014). For this area, MHHW + 36 inches of sea level rise is 9.2 feet NAVD88 (6.2 feet + 3 feet), which could also be reached with lesser amounts of sea level rise in combination with various extreme tide events as listed in Section 5.1.

5.2.3 WAVE DATA AND ANALYSIS

Wave data were primarily used in developing the conceptual design of the breakwater and not the living levee. This data was used to determine the magnitude of wave height, wave period, and wave direction which the breakwater would be designed to withstand. Wave data were obtained from MIKE21 model output from a regional San Francisco Bay modeling study completed as part of the FEMA San Francisco Bay Area Coastal Study (DHI 2011). The modeling study spanned a 31-year period from January 1, 1973 to December 31, 2003. The modeling included both Pacific Ocean swell[44], which propagates through the entrance of San Francisco Bay and tends to have longer periods, and locally-generated, short period wind waves (also known as seas). Five model output points from the MIKE21 model were selected within the focus area to assess the wave conditions and determine the design wave parameters (Figure 5-4). Wave parameters for both swell and seas are nearly identical at all wave stations and Station 927 (Figure 5-4) was selected as a representative station.

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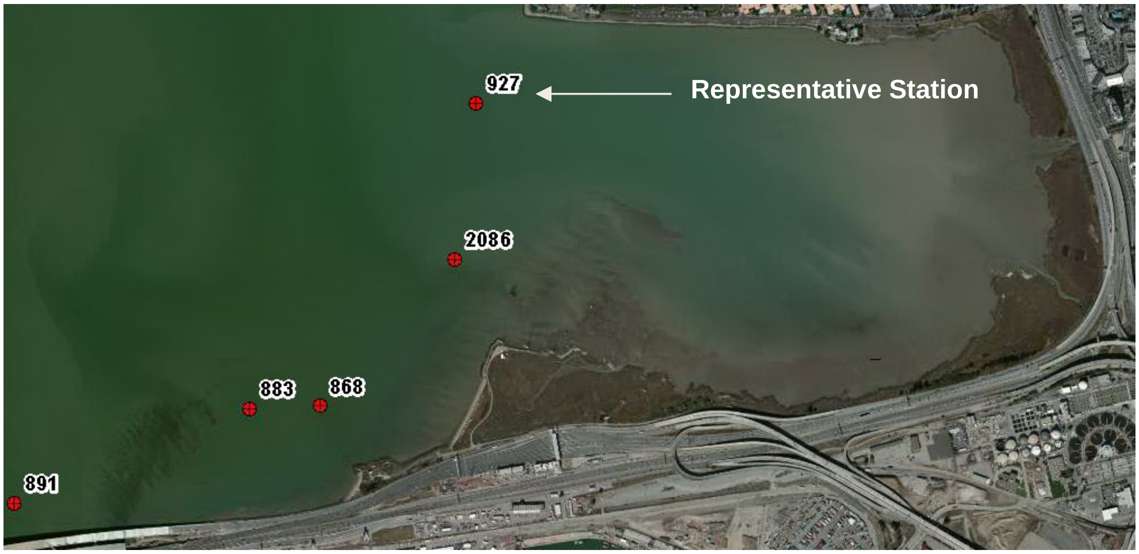
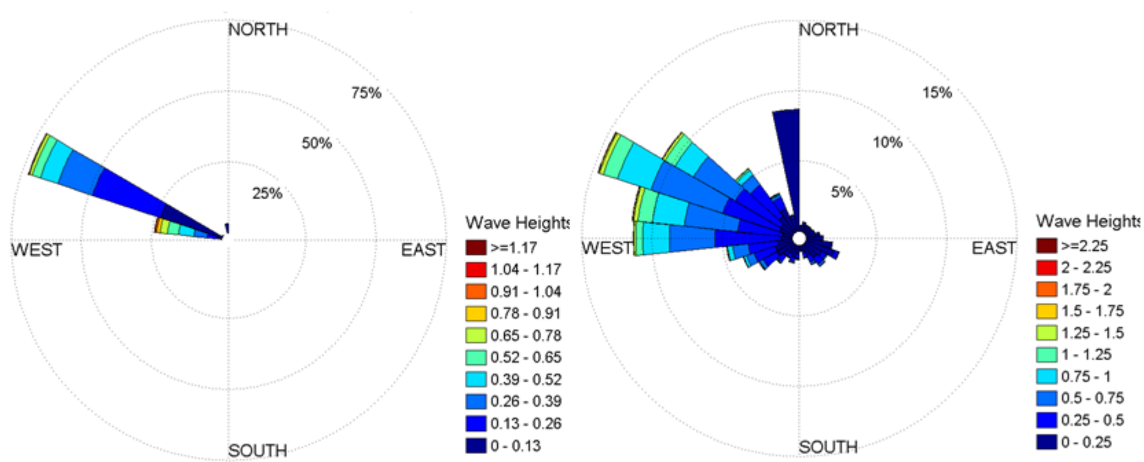
44 The term “swell” is used to describe to describe a specific type of wave. Swells are waves not produced by the local wind and come in at a higher period (longer wave length) than waves produced by the local wind.

Figure 5-4: MIKE21 model output stations selected to assess both swell and seas conditions within the focus area. Station 927 was used as a representative station



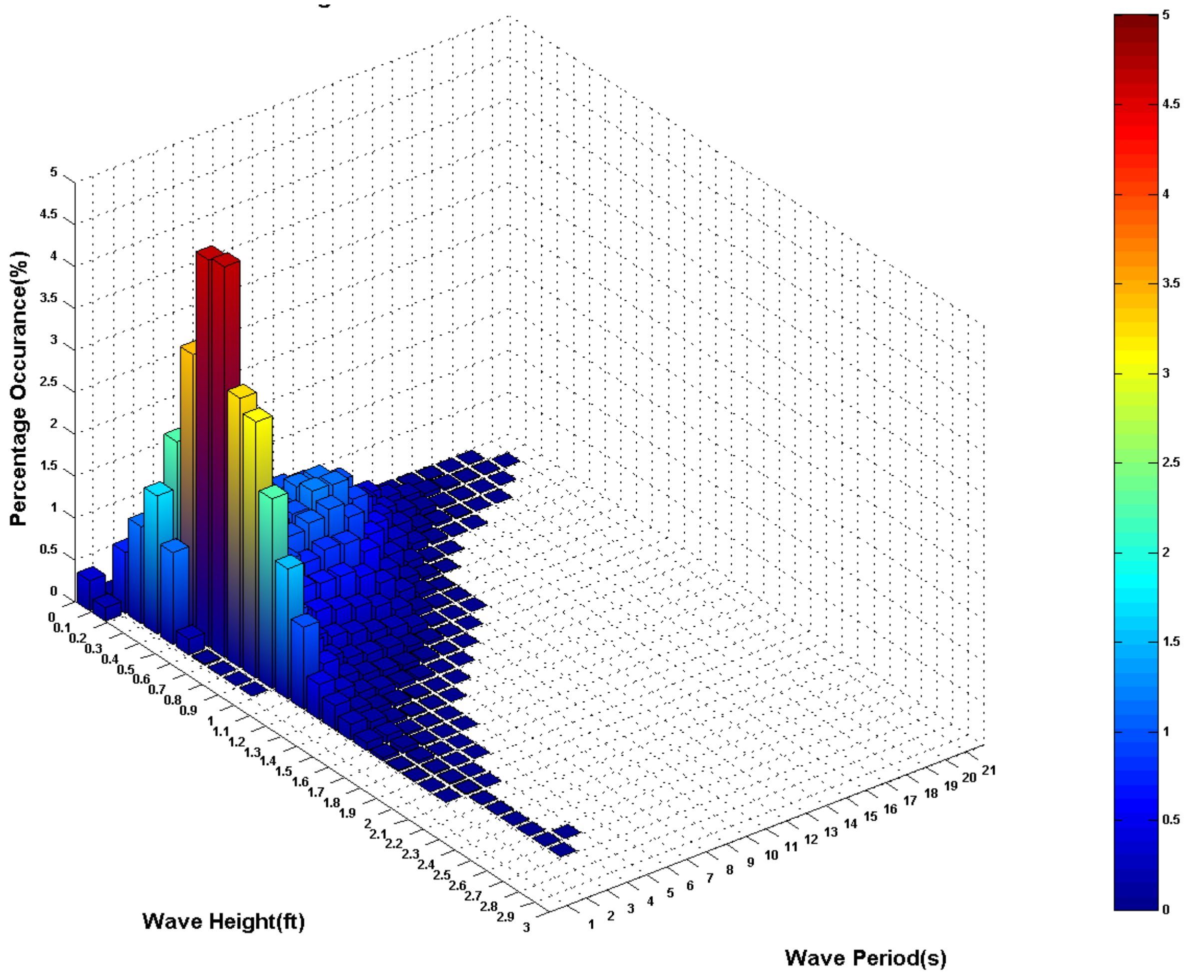
This area is only exposed to swell and seas that approach from the northwest and it is protected from swell and seas that approach in all other directions (Figure 5-5). Swell significant wave heights (H_S) at Station 927 range from approximately 0 - 1.2 feet and seas significant wave heights range from approximately 0 – 2.7 feet. In areas where both seas and swells may be important, wave characteristics can be combined to develop design conditions (FEMA 2008). Significant wave heights and peak spectral periods (T_P) for both swell and seas were combined following guidelines in FEMA (2008) to generate a 30-year time series of combined H_S and T_P values (Figure 5-6).

Figure 5-5: The Distribution of significant wave heights (HS) and direction at station 927 for swell (left) and seas (right)



The breakwater was designed (at a conceptual level) for the 4-percent annual-chance wave height (*H*), or a wave height with an approximate 25-year return period. A 25-year wave height is appropriate for this structure as it is not protecting marina infrastructure, which is typically in the water. Furthermore, designing for a higher wave height (e.g., a 50-year or 100-year wave height) would most likely impede all wave energy from the site and it is preferable to preserve some of the wave energy so that sediment drift and other geomorphic characteristics of the site are preserved. A generalized extreme value (GEV) analysis was used to determine this statistical height from the combined DHI data. These parameters were determined by using algorithms for GEV statistical analysis built into Wave Analysis for Fatigue and

Figure 5-6: The distribution of combined significant wave heights (HS) and peak spectral periods (TP) at station 927. Once the design wave height was determined, the design period (T = 3.5 seconds) was selected as the period associated with the largest wave heights



Oceanography (WAFO) toolbox for Matlab (WAFO Group 2000). Figure 5-7 shows the GEV results for the swell, seas, and combined swell and seas. The 25-year wave height for the combined swell and seas is approximately 2.6 ft. If the seas data had been used exclusively without swell data, the 25-year wave height would be slightly smaller at 2.5 ft.

The design period (*T*) was selected as the wave period associated with the largest wave heights following guidelines in the U.S. Army Corps of Engineers Coastal Engineering Shore Protection Manual (SPM; USACE 1984). As shown in Figure 5-6, this wave period duration is 3.5 seconds. The design wave direction was selected as 285 °TN, which is the most frequently observed direction in the seas data (Figure 5-5). The design wave conditions are summarized in Table 5-2. It is important to note that Baker AECOM (2013) determined two 100-year wave scenarios for this area: *H* = 2.5 feet, *T* = 3.0 seconds and *H* = 3.3 feet, *T* = 3.5 seconds. These are provided for comparison, and although these are 100-year scenarios, and expected to be more severe, they compare reasonably well to the design wave characteristics in Table 5-1.

Figure 5-7: GEV results for swell, seas, and combined swell and seas significant wave heights. The design wave height was selected as the 25-year wave height for the combined data (*H* = 2.6 feet)

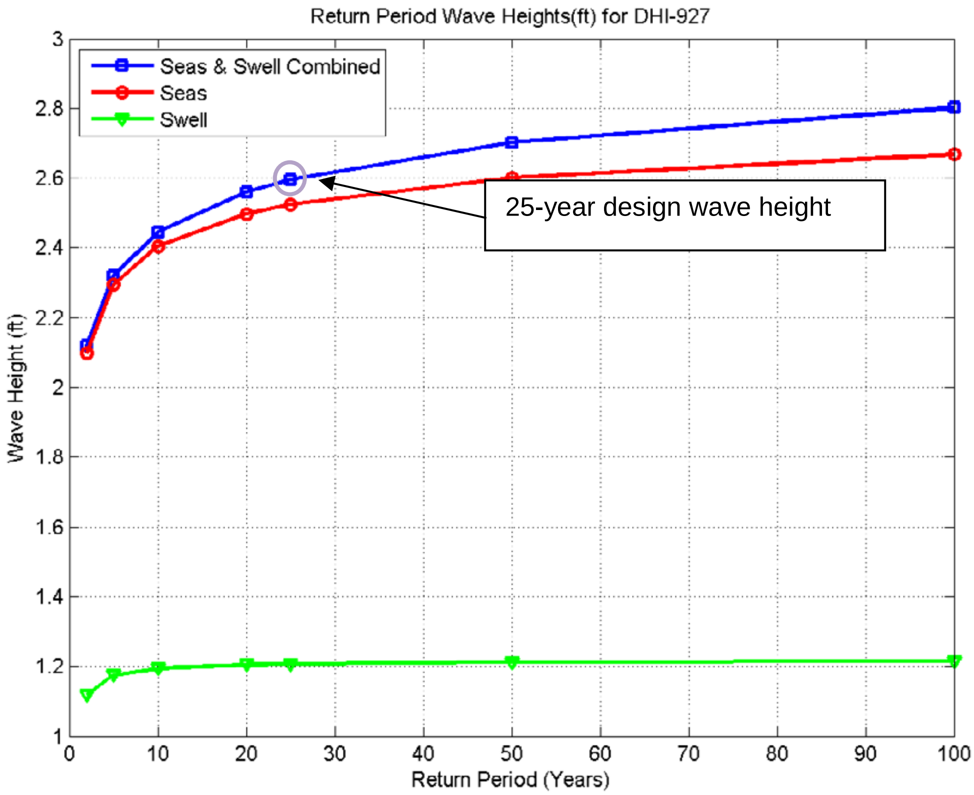


Table 5-2: Design Wave Conditions

WAVE HEIGHT (FT.)	WAVE PERIOD (S)	WAVE DIRECTION (DEGREES TN)
2.6	3.5	285

5.3 CONCEPTUAL DESIGNS

Using the environmental data and design conditions described above, AECOM developed conceptual designs for a living levee and offshore breakwater. The design of the living levee is described in Section 5.3.1 and the design of the breakwater is described in Section 5.3.2.

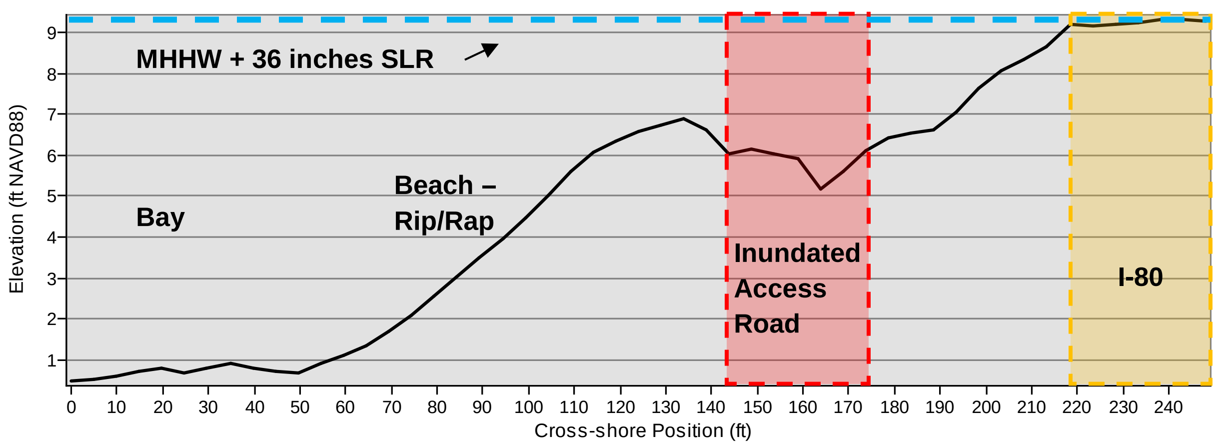
5.3.1 CONCEPTUAL DESIGN OF THE LIVING LEVEE

AECOM performed a site visit on March 7, 2014 with BCDC, MTC, BART, and Caltrans staff. A visual inspection of shoreline protection structures and assets was performed along the northern shorelines of the area, including the dirt access road adjacent to I-80. Localized inundation under existing conditions (MHHW = 6.2 feet NAVD88) was observed along the dirt access road (Figure 5-8).

A detailed review of the DEM revealed that the average elevation of the access road is approximately 7 feet NAVD88 with elevations of daily inundated low spots less than 6 feet NAVD88. Marsh and beach elevations seaward of the access road are much lower. The inundation maps for the 36 inch SLR scenario (Figure 5-2) and a cross-shore profile of the beach and inundated access road immediately west of the toll plaza (Figure 5-9) show that the entire backshore, access road, and a section of I-80 will be

Figure 5-8: A field site photo (looking east) of the dirt access road adjacent to I-80. Effects of daily inundation at high tide (MHHW = 6.2 feet NAVD88) were observed at low spots on the road

Figure 5-9: Cross-shore profile of the inundated access road adjacent to I-80, immediately west of the toll plaza under MHHW + 36 inches SLR conditions



inundated at a SWL of 9.2 feet NAVD88 (i.e., MHHW+ 36 inches of sea level rise). Among the potential adaptation strategies proposed for this focus area in the initial stages of this study (see Compendium of Strategies in Appendix C for more information) the installation of a coastal dune was highlighted as a strategy to protect against flooding. However, coastal dunes are highly erodible, and while they can protect against temporary, episodic attack from waves they don't typically afford protection against permanent SLR. In response to SLR, coastal dunes typically shift landward and upwards to reach a new equilibrium (Bruun 1962). The backshore in this area is constrained by I-80 and there is no room for a dune to shift landwards in response to SLR. A dune placed here would most likely erode away unless the area was heavily nourished to build out the beach substantially. Even then it is not clear that a dune would survive; therefore AECOM proposes a conceptual design of living levee that can be placed adjacent to I-80 and provide SLR protection.

A traditional levee would most likely provide adequate protection against SLR, however it would not provide additional marsh habitat. Furthermore, traditional levees typically appear "engineered" and can detract from the natural aesthetics of the shoreline. A living levee[45] typically has a flatter seaward slope to allow for the planting of vegetation and the creation of marsh habitat (USACE 1994; CDWR 2012). The flatter slope will help dissipate wave energy more than the steeper slope of a traditional levee. Living levees can also be built to accommodate wildlife corridors if required. Because of its larger cross-sectional area, the living levee will also have sufficient accommodation space to allow for future adaptive management efforts that may be needed as sea levels continue to rise.

A living levee was designed following guidelines and specifications in (USACE 1994) and (CDWR 2012). The approximate placement and footprint of the living levee is shown in Figure 5-10. This placement will protect the westbound lanes of the I-80 approach, including the toll plaza. This placement would require that the dirt access road currently adjacent to I-80 be moved to the top of the levee; however, it is noted that placement of the access road on top of the levee could inhibit access to the radio towers and other infrastructure in this vicinity. It is possible that a separate levee will be required to elevate and protect the north-south dirt road used to access the radio towers. This infrastructure is owned and operated by the Port of Oakland and access needs should be vetted with the city and other stakeholders before proceeding further in the conceptual design process. This layout will protect the three inundation sites along I-80 (Figure 5-2). The ends of the levee will need to be tapered such that the design slopes are maintained. The details of these ends will be resolved if this strategy proceeds to the detailed design phase.

The height of the living levee conceptual design was selected so that it would meet the FEMA levee height accreditation criteria, and also meet BCDC's climate change policies that require larger shoreline projects be resilient to mid-century sea level rise conditions, and be capable of being adaptively managed to end of century conditions. To meet FEMA levee height criteria, the levee crest elevation would need to meet the higher of two criteria: 2 feet of freeboard above the 100-year SWL, or 1 foot of freeboard above the maximum expected wave run-up elevation (see Table 5-3). Typically, the wave runup criterion controls the levee height; however, the living levee can be designed to reduce the potential for wave runup. Additionally, if the breakwater was also constructed, the potential for wave runup would be even further reduced. Therefore, the levee crest elevation was designed to meet 2 feet of freeboard above the 100-year SWL.

The current estimated 100-year SWL in this area is 9.8 feet NAVD88 (BakerAECOM 2013), which is approximately 3.6 feet higher than current MHHW. To ensure the levee would be resilient to mid-century, 1 foot of SLR was added to the 100-year SWL in the conceptual design. Finally, to determine if the levee could be adaptively managed to end of century, 3 feet of sea level rise was added to the current 100-year SWL in order to understand how the living levee may need to be modified or adapted to meet end-of-century conditions.

A cross-section of the conceptual design of the living levee is shown in Figure 5-11. The design slope of the levee on the landward side is the maximum recommended 2:1 (H:V). The seaward slope is a much flatter 5:1 (H:V) to accommodate intertidal marsh and upland habitat. It has a crest elevation of 14.8 feet NAVD88 and a width of 16 feet to accommodate the existing access road that will be inundated from SLR.

[45] A living levee is a structure which couples multiple benefits, including flood protection and habitat restoration or creation. Typical flood protection levees do not incorporate "living" or vegetated elements; whereas a living levee seeks to maximize the inclusion of vegetation in order to create valuable habitats and create habitat corridors which can link critical habitat areas together. Living levees can be found in both coastal and riverine environments.

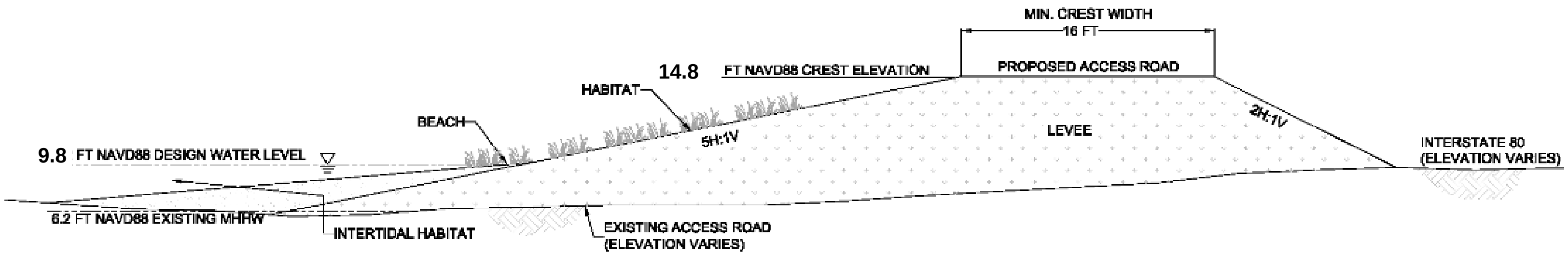
Figure 5-10: Approximate footprint of the living levee designed to protect I-80 from inundation under 36 inches of SLR. This particular placement will protect the three inundated (sites A, B, C in Figure 5-2)

Table 5-3: FEMA Freeboard Requirements for Levee Accreditation

WATER LEVEL	WATER LEVEL ELEVATION (FEET NAVD88)	WITH SLR	FEMA REQUIRED LEVEE CREST ELEVATION (FEET NAVD88)
12 inches SLR			
MHHW	6.2	7.2	N/A
100-year SWL	9.8	10.8	10.8 + 2 =12.8
100-year TWL	10.7	11.7	11.7 + 1 = 12.7
36 inches SLR			
MHHW	6.2	9.2	N/A
100-year SWL	9.8	12.8	12.8 + 2 = 14.8
100-year TWL	10.7	13.7	13.7 + 1 = 14.7

* Controlling design crest elevation

Figure 5-11: A cross-section of the designed living levee. In this design, the existing access road is moved to the crest of the levee. As the levee itself will not compensate for lost beach and marsh habitat due to SLR, it is recommended that sandy beach or marsh sediment be subsequently placed seaward of the levee. Appropriate beach grass or marsh plants could be planted in this area



In the event of higher than anticipated SLR, the 2 feet of freeboard can provide additional protection; however at some point the levee crest height will likely need to be increased. This could be achieved by projected the levee slopes up to the required elevation; however, this will reduce the width of the access road. If the access road needs to retain the specified width, the entire footprint of the levee will need to be widened either seaward or towards I-80. As this strategy moves to the detailed design phase, the levee footprint could be increased and the levee could be constructed with a broader slope to increase the capacity for future adaptive management. Alternatively, the levee could also be designed initially for a higher SLR scenario if desired.

It is anticipated that SLR will impact the beach and marsh bayward of the proposed levee (Figure 5-2), and the levee footprint will also impact some existing marsh areas. However, the gentle slope on the bayward side will add considerable habitat space to compensate for the marsh areas that may be lost, and vegetation plantings can enhance the additional habitat space. While the conceptual design did not include the placement of a sandy beach or the creation of marsh habitats bayward of the living levee, these additional features could also compensate for the natural beach and marsh habitat that would be lost due to SLR, in particular if they are planted with either beach grass or saltwater-tolerant plants.

Overall, the conceptual design presented will protect an area that is already low-lying and vulnerable to sea level rise in a manner that preserves the natural aesthetic of the shoreline. This conceptual design is also consistent with the region’s desire for the use of innovative sea level rise adaptation approaches, and with the vision outlined in the Gateway Park Project Concept Report (GPWG 2012).

Caltrans operates and maintains several drainage structures along the existing dirt access road adjacent to I-80 (Figure 5-12), and the living levee will most likely impact these structures. Although the living levee could be interspersed with segments of traditional levee, with steeper slopes and a narrower footprint, where these or other drainage structures are impacted, it is likely that these structures are themselves vulnerable to sea level rise and will need to be re-designed or re-located. A complete drainage study should be conducted before the living levee, or any other adaptation measures, are contemplated to ensure the approaches and the toll plaza can maintain effective drainage as sea level rise.

For FEMA accreditation, the conceptual design includes 1 foot of freeboard above the approximate maximum expected run-up elevation.

5.3.2 CONCEPTUAL DESIGN OF OFFSHORE BREAKWATER

The living levee will help protect the shoreline from inundation due to SLR. However, it is anticipated that wave overtopping and wave-induced erosion of the existing shoreline, and potentially the levee itself, will increase with SLR. To help reduce the potential for wave runup, overtopping and erosion of the living, and to encourage the sustainability of the natural wetlands in the Emeryville Crescent area, AECOM developed a conceptual design for an offshore breakwater. Figure 5-13 shows the proposed placement, orientation, and length of the breakwater offshore of Radio Beach. Wave diffraction analysis was performed using the design wave conditions and following the guidelines in the U.S. Army Corps of Engineers Coastal Engineering Manual (CEM; USACE 2012) to determine the configuration that will reduce the design wave height by at least half ($H/2$ = 1.3 feet) for the entire focus area, from the western pocket beach adjacent to I-80 to the eastern edge of the marsh point, approximately 2500 feet east of the toll booth. Waves with a period of 3.5 seconds are in deep water at this site. Reducing the wave height by at least half will protect the area from wave overtopping while allowing some smaller diffracted waves into Radio Beach.

Figure 5-12: A site photo (looking east) of the dirt access road adjacent to I-80. One of many drainage structures owned and operated by Caltrans, can be seen adjacent to the road

Figure 5-13: A potential breakwater placement and configuration offshore of Radio Beach that will minimize wave action and overtopping with 36 inches of SLR. The protected area where the wave heights will be reduced by at least half due to diffraction is shown within the dotted lines.

The larger northeastern segment of the breakwater is oriented perpendicular to the design wave direction (285 degrees TN). The shorter southwestern segment is oriented at approximately 50 degrees TN to minimize impacts to longshore sediment transport. Longshore transport in this area is generally to the northeast and it is anticipated that this will need to be preserved to maintain the health of the beach and marsh complex.

The breakwater dimensions were determined using the average elevation of the seabed along the proposed breakwater footprint (-3.5 ft. NAVD88), the design wave and water level conditions, and the guidelines and standards in the SPM and CEM (USACE1984; 2012). Rocks were sized with the Hudson Equation following the procedure outlined in the SPM (UACE 1984). Assuming a structure slope of 2:1 (H:V), a non-breaking design wave (the design wave would be in deep water), and an armor layer consisting of rough, angular quarry stone, the median rock diameter (D_{50}) was calculated as 1.0 ft. The values used in the calculation are summarized in Table 5-4.

Table 5-4: Summary of the Armor Stone Size Calculation Using the Hudson Equation Following the SPM (USACE 1984)

PARAMETER	VALUE	DESCRIPTION
H	2.6 ft.	Design wave height
W_r	165.0 lb./ft^3	Specific weight of stone
W_w	64.0 lb./ft^3	Specific weight of water
S	2.6	Specific gravity of stone
cot α	2:1	Structure slope (H:V)
K_d	2.0	Hudson coefficient for rough, angular quarry stone and a non-breaking wave
W_{50}	184.5 lb.	Calculated median weight of each armor stone
V_{50}	1.1 ft^3	Calculated median volume of each armor stone
D_{50}	1.0 ft.	Calculated median diameter of each armor stone

As the wave heights are relatively small in this area, a two layer breakwater consisting of an armor layer and a core was considered. The required range of stone sizes for each layer was calculated following the procedure outlined in the Automated Coastal Engineering System (ACES, USACE 1992) and the CEM (USACE 2012) (Table 5-5).

Table 5-5: Rock Size Gradations for the Armor Layer and Core Following the ACES (USACE 1992) and the CEM (USACE 2012)

LAYER	REQUIRED ROCK SIZE GRADATION	WEIGHT RANGE (LB)	DIAMETER RANGE (IN)
Armor	0.75 W_{50} – 1.25 W_{50}	138.4 – 230.6	10 – 14
Core	0.7 W_{50}/10 – 1.30 W_{50}/10	12.9 – 24.0	2 – 4

MHHW + 36 inches of SLR (9.2 feet NAVD88) was used as the SWL for the offshore breakwater. Unlike the living levee, the 100-year SWL was not used to design this structure because breakwaters are not typically designed for a 100-year timeframe. The required breakwater freeboard was determined using guidance provided in CEM (USACE 2012) for a design with limited to no wave overtopping and no damage. Parameters used in the calculations are summarized below in Table 5-6. For these design wave conditions, the CEM specifies a maximum overtopping discharge of 1.8 ft^3/s. Using this discharge rate with tables in the CEM, the required freeboard was determined as 1.2 ft. Adding 1.2 feet of freeboard to the SWL requires that the breakwater crest be built to 10.4 feet NAVD88, which is rounded to 10.5 feet NAVD88 to be conservative for the conceptual design (see Figure 5-14).

Figure 5-14: A cross-section of the designed breakwater. The total design height and width are 14 feet and 78 feet respectively

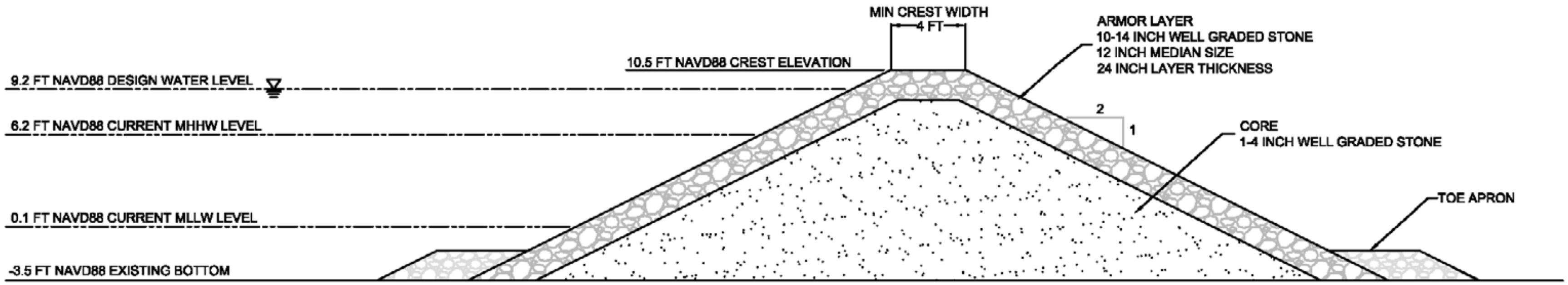


Table 5-6: Summary of the Breakwater Freeboard Calculation Following the CEM (USACE 2012)

PARAMETER	VALUE	DESCRIPTION
H	2.6 ft.	Design wave height
T	3.5 s	Design wave period
g	32.2 ft./s	Acceleration due to gravity
cot α	2:1	Structure slope
S_{op}	0.04	Ratio between design wave height and deepwater wave length
X_{op}	9.83	Iribrarren Number
g_r	0.55	Factor for surface roughness
g_b	1	Factor for berm
g_h	1	Factor for shallow water
g_β	1	Factor for incident wave angle
$q_{threshold}$	1.8 ft^3/s	Average threshold overtopping discharge
q	1.8 ft^3/s	Average overtopping discharge
R_c	**1.2 ft.**	**Required freeboard**

The total design height (from base to crest) and width are 14 feet and 78 feet respectively. The overall design length, including both segments, is approximately 3050 feet. The design includes a toe apron that should be placed at the toe to prevent toe scour and subsequent damage and settling. At this time, it is unknown if the breakwater would continue to function for greater amounts of SLR then currently projected for end of century. If SLR rates do not dramatically accelerate and do not greatly exceed current projected levels within the breakwater's estimated lifespan, it is possible that the structure will require minimal maintenance and no major alterations. If SLR greatly exceeds current projections then the crest of the breakwater will most likely need to be elevated accordingly and the footprint widened. As this strategy moves to the detailed design phase, the footprint or the design elevations could be increased to accommodate higher SLR amounts if desired.

It is possible that the installation of a seawall adjacent to I-80 would protect the areas from both inundation and wave overtopping. This strategy might preclude the installation of both the living levee and breakwater. However, a seawall would not enhance the natural marsh habitat, as a living levee would, and a seawall would not protect the marsh and shoreline from wave-induced erosion, as a breakwater would. Therefore, if a seawall were installed as the only adaptation strategy, or if a seawall and living levee were installed without a breakwater, the existing natural shoreline and levee would most likely eroded from wave attack. Only the breakwater and living levee combined will offer all of the benefits of protection from inundation, wave overtopping, and wave-induced erosion, and enhancement of the natural shoreline.

5.4 PARTNERS

The strategies described in this section cannot be successfully designed and implemented without the collaboration of relevant local, regional, state, and federal agencies. Such agencies include Caltrans (which owns and maintains the Bay Bridge), the Port of Oakland, Alameda County, East Bay Regional Parks District (EBRPD), BCDC, San Francisco Bay RWQCB, BATA, CDFG, California SLC, California State Parks, NOAA, and USACE. The respective roles of these agencies in designing and implementing these strategies are described in Sections 5.5 and 5.7.

5.5 IMPLEMENTATION STEPS

This section details the steps to implementing both adaptation strategies. The full list of adaptation strategies developed in the initial stages of this study (see Compendium of Strategies in Appendix C for more information) should be reviewed in case a more appropriate strategy can be implemented. Given that these strategies require collaboration among multiple agencies (listed in Section 5.4) and involves large-scale construction in the Bay (which, in turn, can trigger complex environmental/regulatory requirements), the implementation of these strategies could potentially be significantly more time- and cost-intensive, compared to more traditional transportation projects. As a first step in the implementation process, there should be convening and coordination with all critical stakeholders. These include Caltrans, which maintains the drainage structures adjacent to I-80 and other highways, and the Port of Oakland, which operates the radio towers and maintains the dirt access roads. Once concerns are addressed from the stakeholders, a preliminary Environmental Assessment should be conducted to investigate environmental effects. It is important to note that construction of the living levee will impact the marsh and shoreline and construction of the breakwater will impact the nearshore seabed. However, both strategies will positively affect the natural environment as well. The living levee will create new shoreline habitat and the breakwater will prevent wave-induced erosion of the shoreline habitat. It will be critical that the project follows the requirements set forth in the National Environmental Policy Act (NEPA) and the California Environmental Quality Act (CEQA). The structures will need approval by USACE as well as BCDC, which regulates the placement of fill in the Bay, the100-foot shoreline band, salt ponds, managed wetlands, and certain waterways. BCDC must also determine that the fill associated with the project is the minimum necessary, that no upland alternative exists, and that the project is resilient to mid-century and can be adaptively managed to end of century.

One of the first steps in moving beyond conceptual design is conducting detailed bathymetric and topographic survey. These surveys will refine the elevation data and allow for more detailed engineering design of both structures. Geotechnical surveys should be conducted at both sites to provide greater detail on the sediment and soil conditions. This information is required to design against potential settlement, subsidence, and degradation of the structures. After the surveys, detailed engineering drawings would be developed to guide construction. A subsequent construction survey will mark key construction benchmarks at the site. After these steps, the construction phase can begin.

5.6 OPERATIONS AND MAINTENANCE CONSIDERATIONS

AECOM has completed an overview of the expected operations and maintenance activities for both adaptation strategies. Expected operations and maintenance activities for the living levee include:

- All permits need to be current and updated as needed.
- The dirt access road on top of levee (adjacent to I-80) needs to be maintained and in operable condition. Eroded or subsided sections need to be fixed to maintain access.
- The levee needs to be routinely inspected for damage and/or deterioration.
- Sections of the levee that deteriorate due to wave induced erosion or seepage need to be fixed to maintain protection from inundation and flooding.
- Sections of the levee that subside may need to be built higher to maintain protection from inundation and flooding.
- For higher SLR scenarios, localized areas of the levee may need to be built to higher elevations to maintain protection from flooding.
- Vegetation may need to be planted in areas where habitat is degraded.

Expected operations and maintenance activities for the offshore breakwater include:

- All permits need to be current and updated as needed.
- The breakwater needs to be routinely inspected for damage and/or deterioration. This may include underwater inspections.
- Segments that settle may need to be built higher to maintain protection from waves.
- It is expected that the breakwater will occasionally be overtopped and that stones will become displaced. Displaced stones need to be replaced.
- The toe aprons may need to be fixed if damage occurs.
- For higher SLR scenarios, the breakwater may need to be built to higher elevations to maintain protection from wave action.

5.7 REGULATORY CONSIDERATIONS

The implementation of these adaptation strategies will incorporate several different planning and development activities, including coastal flood protection, coastal erosion protection, and nearshore bathymetric and shoreline habitat restoration. In addition, many agencies may exercise regulatory control over this focus area. Therefore, there are unique regulatory criteria for this project. The following is a list of agencies that will require consultations and/or regulatory permits:

- USACE Section 404/10 permit for construction
- NOAA Fisheries (formerly NMFS) Magnuson-Stevens Fishery Conservation and Management Act consultation
- NOAA Fisheries and US Fish and Wildlife Service Endangered Species Act (ESA) Section 10 consultation
- CA Department of Fish and Game (CDFG) California Endangered Species Act (CESA) consultation
- BCDC compliance with the McAteer-Petris Act that promotes responsible planning and to eliminate unnecessary placement of fill (i.e., upland alternative analysis, minimum fill necessary)
- BCDC administration of the Coastal Zone Management Act (CZMA)
- California State Lands Commission (SLC) for Aquatic Lands Lease if located on such lands
- San Francisco Bay Regional Water Quality Board (RWQCB) Clean Water Act (CWA) 401 Water Quality Certification
- RWQCB Porter-Cologne Water Quality Control Act – State law equivalent of the 401 Water Quality Certification
- Alameda County “Land Use Permit” --- More research needed to identify these details
- Alameda County “Flood Plain/Flood Control” --- More research needed to identify these details
- Bay Area Air Quality Management District (BAAQMD) Engine Permit – Required for heavy diesel powered equipment. This may or may not be applicable.

5.8 IMPACT ON ENVIRONMENT, EQUITY, AND MOBILITY

5.8.1 IMPACTS ON ENVIRONMENT

The breakwater and living levee proposed in these strategies serve two different purposes. The breakwater’s purpose is to protect inland areas from wave action, erosion, and/or scour, whereas the living levee is more effective at protecting inland areas from permanent inundation and/or temporary flooding. Therefore, the environmental benefits of these strategies were evaluated by estimating the acres of wetlands within the Bay Bridge Focus Area boundaries that are expected to be protected from either wave action, erosion or scour, or from the magnitude of permanent inundation and/or temporary flooding expected under the baseline scenario for the Bay Bridge Focus Area (MHHW + 36-inch SLR) as a result of the implementation of these strategies. As a first step, the total land area expected to be protected from the aforementioned impacts by the installation of an offshore breakwater and living levee immediately north of I-80 at the San Francisco-Oakland Bay Bridge touchdown was estimated on the basis of factors such as breakwater and living levee placement; the extent of wave action, erosion, or scour; and the extent of inundation and/or flooding projected under the baseline scenario for the Bay bridge focus area. Within the total land area likely to be protected, the acres of existing wetlands were identified using GIS data compiled by the Bay Area Aquatic Resources Inventory (BAARI). This analysis estimates that approximately 40 acres of wetlands could be protected from wave action, erosion, and/or scour as a result of the installation of the breakwater, as the breakwater's proposed location is north of the wetlands. Most of this acreage is characterized as 'Young High Tidal Marsh' in the BAARI database. Table 5-7 provides a breakdown of the acreage of various types of wetlands that could be protected from wave action, erosion, and/or scour by the breakwater.

Table 5-7: Acres of Protected Wetlands from Wave Action, Erosion, and/or Scour by Type, Bay Bridge Focus Area

TYPE OF WETLANDS	ACREAGE PROTECTED
Bay Flat	5
Young High Tidal Marsh[46]	35
Total Acreage of Wetlands Protected	**40**

The proposed location of the living levee indicates that it will not contribute to the protection of wetlands in this area. The main purpose of the living levee is to protect transportation assets directly south of the wetlands, and therefore its proposed location is south of the wetlands and immediately north of I-80. Given that there are no wetlands located south of the living levee, the environmental benefit analysis is not applicable to the installation of the living levee.

It should be noted that this analysis does not take into consideration additional wetlands or habitat that may be created as a result of the living levee. It should also be noted that this analysis does not consider how wetland or habitat areas will change and when this focus area system finds equilibrium in response to the proposed strategy. For example, changes may occur in sediment transport patterns, or in the spatial extents of the shoreline in response to the implementation of the breakwater, which are not considered in the estimate of wetland acreage protected by this strategy.

The breakwater itself could provide a safe habitat for birds to perch during calm conditions.

5.8.2 IMPACTS ON EQUITY

The breakwater and living levee proposed in these strategies serve two different purposes. The breakwater's purpose is to protect inland areas from wave action, erosion, and/or scour, whereas the living levee is more effective at protecting inland areas from permanent inundation and/or temporary flooding. Therefore, the social benefits of these strategies were evaluated by estimating the population and number of jobs within the Bay Bridge Focus Area boundaries that are expected to be protected from either wave action, erosion or scour, or from the magnitude of permanent inundation and/or temporary flooding expected under the baseline scenario for the Bay Bridge Focus Area (MHHW + 36-inch SLR) as a result of the implementation of these strategies. As a first step, the total land area expected to be protected from the aforementioned impacts by the installation of an offshore breakwater and living levee immediately north of I-80 at the San Francisco-Oakland Bay Bridge touchdown was estimated on the basis of factors such as breakwater and living levee placement; the extent of wave action, erosion, or scour; and the extent of inundation and/or flooding projected under the baseline scenario for the Bay bridge focus area. Within the total land area likely to be protected, the number of protected residents and jobs was estimated using GIS data provided by the Metropolitan Transportation Commission (MTC) on population and employment projections under Plan Bay Area's "Preferred Scenario"[47] for the year 2040. It was found that the land area likely to be protected immediately south of the breakwater or living levee does not include any residential or commercial zones. Therefore, this social benefit analysis is not

46 Young High Tidal Marsh refers to recently established high marsh vegetation. It includes vegetation that grows at the higher end of the tidal phase (at the MHHW level).

47 The "Preferred Scenario" is a planning scenario for the Bay Area's Sustainable Communities Strategy (SCS) and Regional Transportation Plan (RTP) that articulates the Bay Area's vision of future land uses and transportation investments, against which the region's performance relative to statutory greenhouse gas and other voluntary performance targets are measured.

applicable to these strategies. However, it should be noted that these strategies would result in indirect social and economic benefits by protecting a transportation corridor that includes commute routes for thousands of commuters, including those living in disadvantaged communities.

5.8.3 IMPACTS ON MOBILITY

These strategies could potentially prevent adverse impacts on mobility from disruptions in operations in both transit and roadway systems, which would otherwise occur under the baseline scenario for the Bay Bridge Focus Area (MHHW + 36-inch SLR). The following adverse impacts are expected to occur under the baseline scenario in the absence of the implementation of these strategies. A description of the methodology used to quantify each of these impacts is provided in Table 4-5 under Chapter 4, Section 4.4.1.

Table 5-8: Impacts avoided through implementation of strategy

AVOIDED IMPACT	DAILY CHANGE (PERCENTAGE CHANGE)	AVOIDED DAILY COST ($)*
Increase in vehicle miles traveled (passenger vehicles)	+4,102,540 (+3%)	$1,899,830
Increase in vehicle miles traveled (trucks)	+439,014 (+3%)	$458,135
Increase in vehicle hours traveled (passenger vehicles)	+214,888 (+6%)	$2,686,100
Increase in vehicle hours traveled (trucks)	+20,834 (+6%)	$597,936
Increase in vehicle hours of delay (passenger vehicles)	+136,830 (+40%)	Not available
Increase in vehicle hours of delay (trucks)	+12,613 (+48%)	Not available
Number of # of transit routes impacted in or within ½ mile of communities of concern (AC Transit ***local routes***)	1	None
Number of # of transit routes impacted in or within ½ mile of communities of concern (AC Transit ***trans-bay routes***)	27	None
Increase in GHG emissions from all on-road vehicles (tons/ day)	+113,532 (+3.0%)	$2,611,236
Increase in Criteria Air Pollutant emissions (tons/ day)	See below	
ROG	+31.0 (+2.6%)	None
NOx (Summertime)	+49.0 (+2.4%)	$847,700
CO	+248.0 (+2.9%)	$18,600
PM10	+42.0 (+2.6%)	$5,875,800
PM2.5	+10.2 (+2.7%)	None
NOx (Wintertime)	+54.2 (+2.5%)	None
Total Estimated Daily Avoided Costs to the Region		**~$15 Million**

*Cost valuations are rounded to the nearest $100,000, and are based on Caltrans' Life-Cycle Benefit-Cost Analysis Economic Parameters (2012)48, as applicable (in 2012 dollars). VMT costs include vehicle operating expenses assessed directly to vehicle owners (fuel and wear & tear expenses). Emissions costs reflect "health costs" to the public (such as costs of hospitalizations, disease, and mortality). Fuel economy estimates are for 2011 fleet49.

As a result of the implementation of these strategies, the aforementioned estimated increases in vehicle miles traveled, vehicle hours traveled, and vehicle hours of delay could be prevented. In turn, the increase in GHG and criteria air pollutant emissions, which is directly related to vehicle miles traveled, are also expected to be prevented. Additionally, it is estimated that disruptions to local and trans-bay transit routes in or within ½ mile of communities of concern (CC) could be prevented.

5.9 PLANNING LEVEL COST ESTIMATION

AECOM has developed conceptual-level cost estimates for the implementation of both strategies based on similar projects constructed in similar environments. The costs for the living levee are detailed in Table 5-9 and include the units, quantities, unit prices, and item prices. Important items in the costing estimate

[48] http://www.dot.ca.gov/hq/tpp/offices/eab/benefit_cost/LCBCA-economic_parameters.html
[49] http://www.eia.gov/totalenergy/data/monthly/pdf/sec1_17.pdf

Table 5-9: Conceptual-Level Cost Estimate for the Living Levee

	ITEM	UNITS	QUANTITY	UNIT PRICE	ITEM PRICE
1	Project Mobilization/Demobilization (10% of base construction cost)	%	10		$266,250
2	Clearing & Demolition/Disposal	LS	1	$170,000	$170,000
3	Signage and Traffic Control	LS	1	$15,000	$15,000
4	Survey	LS	1	$20,000	$20,000
5	Levee Construction	LF	3,500	$625	$2,187,500
6	Levee Road Construction	SY	7,000	$18	$126,000
7	Plantings (in Place)	SY	16,000	$9	$144,000
9	**Sub-Total 1: Estimated Base Construction Cost:**				**$2,928,750**
10	Sales Tax @ 8.75% of Base Construction Cost				$256,266
11	**Sub-Total 2: Estimated Base Bid:**				**$3,185,016**
12	Permitting and Design (12% of base construction cost)	%	12		$351,450
13	Bidding/Contract Admin/Construction Oversight (10% of base construction cost)	%	10		$292,875
14	Concept Level Contingency (40% of Project Costs)	%	40		$1,531,736
15	**Total Estimated Project Cost:**				**~$5.4 Million***

*The total estimated projected cost has been rounded to the nearest $100,000.

include initial topographic and geotechnical surveys which are required to refine the design to construction specifications. They also include subsequent clearing and demolition/ disposal which will be necessary to prepare the site. Costs of construction of the living levee and dirt access road are included. Finally, costs associated with the placement of habitat sediments and vegetation plantings, including salt tolerant dune grasses, are detailed. It is important to note that this appears to be relatively simple construction with limited complexity so a 20-30% concept level contingency could be considered typical. However, there are high levels of uncertainty associated with the site conditions, design and construction criteria and constraints, permit/regulatory requirements, and some item costs. To account for these uncertainties a slightly higher contingency of 40% is used in Item 14. The total estimated project cost is approximately $5.4 Million. It is important to note that once the project proceeds to the design phase, a detailed geotechnical survey will be required to determine the type of necessary core. This information will, most likely, change the conceptual cost outlined below. It should be noted that sheet piles are not included in the designs or cost estimates, as they are not typically used as structural components for living levees. Costs for obtaining permits and completing the necessary CEQA/NEPA review are not included in the conceptual cost estimate. Overall design costs are included in Item 12.

A conceptual-level cost estimate for the installation of the offshore breakwater is shown in Table 5-10. Important items in the costing estimate include initial bathymetric and geotechnical surveys which are required to refine the design to construction specifications. They also include subsequent clearing and demolition/disposal which may be necessary to prepare the site. Costs of construction of the breakwater, including placement of the armor stone, core material, toe aprons are included. It is important to note that this appears to be relatively simple construction with limited complexity so a 20-30% concept level contingency could be considered typical. However, there are high levels of uncertainty associated with the site conditions, design and construction criteria and constraints, permit/regulatory requirements, and some item costs. To account for these uncertainties a slightly higher contingency of 40% is used in Item 12. The total estimated project cost is approximately $11.6 Million. It should be noted that sheet piles are not included in the designs or cost estimates, as they are not typically used as structural components for breakwaters. Costs for obtaining permits and completing the necessary CEQA/NEPA review are not included in the conceptual cost estimate. Overall Design costs are included in Item 10.

Table 5-10: Conceptual-Level Cost Estimate for the Offshore Breakwater

	ITEM	UNITS	QUANTITY	UNIT PRICE	ITEM PRICE
1	Project Mobilization/Demobilization (10% of base construction cost)	%	10		$577,500
2	Survey	LS	1	$50,000	$50,000
3	Core Material (In Place Cost)	Ton	54,000	$55	$2,970,000
4	Armor Stone (In Place Cost)	Ton	26,000	$85	$2,210,000
5	Navigation Markers	LS	1	$20,000	$20,000
6	Mitigation Measures (10% of base construction cost)	%	10		$525,000
7	**Sub-Total 1: Estimated Base Construction Cost:**				**$6,352,500**
8	Sales Tax @ 8.75% of Base Construction Cost				$555,844
9	**Sub-Total 2: Estimated Base Bid:**				**$6,908,344**
10	Permitting and Design (12% of base construction cost)	%	12		$762,300
11	Bidding/Contract Admin/Construction Oversight (10% of base construction cost)	%	10		$635,250
12	Concept Level Contingency (40% of Project Costs)	%	40		$3,322,358
13	**Total Estimated Project Cost:**				**~$11.6 Million***

*The total estimated projected cost has been rounded to the nearest $100,000.

5.10 CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

There are many potential adaptation strategies that could be implemented to protect against SLR and storm surge in this focus area. An initial review of the focus area and of SLR and storm surge conditions indicated that an artificial dune alone would most likely not adequately protect I-80 and the Toll Plaza from these impacts. Therefore, AECOM conceptually designed a living levee that could be placed to protect these assets. AECOM also developed a conceptual breakwater design that will reduce wave heights and the anticipated increase in wave overtopping and wave-induced erosion that will accompany SLR and storm surge in the focus area.

In the conceptual design for the living levee, some needs for further investigation have been identified. The living levee design requires moving the access road for the radio towers to the top of the levee, and at this time it is not known if this placement would meet the access needs of the Port of Oakland and other current stakeholders in this area. Secondly, the living levee structure will not protect the beach and marsh from SLR; however it will create significant intertidal and upland habitat area on the seaward slope. In addition to the habitat created on the seaward slope, either sandy beach or marsh sediment could be placed seaward of the levee to further increase habitat. Although the conceptual living levee design includes this consideration, determining the feasibility of habitat creation will require a more thorough analysis before this strategy can be moved forward in the design process.

5.11 REFERENCES

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Adaptation Strategy: Damon Slough Living Levee

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6. ADAPTATION STRATEGY: DAMON SLOUGH LIVING LEVEE

This section presents the preliminary conceptual design and cost estimate for a potential living levee system[50] adaptation strategy along both sides of Damon Slough within the Oakland Coliseum Focus Area. The conceptual living levee spans the length of Damon Slough, has a crest elevation appropriate to protect against flooding from at least a mid-century sea level rise (SLR) magnitude coupled with a 100-year extreme tide event. The levee system can be adaptively managed for the likely magnitude of sea level rise expected by end-of-century (e.g., 36 inches). It is important to note that a broader suite of strategies will be necessary to address other vulnerabilities identified in the focus area in tandem with this strategy.

Following the development of detailed inundation maps and an assessment of coastal and riverine flooding, several adaptation strategies were proposed that could protect sections of the I-880 Damon Slough Bridge, the Oakland Coliseum Complex, Oakland Coliseum Amtrak Station, Oakland Coliseum BART Station, and the Oakland Airport Connector from SLR, storm surge, and riverine flooding. This section explores the feasibility of installing a living levee to reduce the potential for future flooding; however, it should be noted this focus area already has riverine flooding concerns under existing conditions. A living levee is one of several adaptation strategies identified for this focus area in the initial stages of this study (See Compendium of Strategies in Appendix C for more information). It is possible that the existing land uses in the Coliseum Focus Area may change over the next decade, which could allow for a wider suite of potential adaptation strategies. Before implementing this strategy, the timing of land use changes in the Coliseum Focus Area, including redesign or removal of the Coliseum Complex, should be considered and the full list of options should be reviewed[51].

The following sections provide a description of the Coliseum Focus Area (Section 6.1), a description of preliminary coastal engineering analysis and the development of design criteria for the proposed strategy (Section 6.2), conceptual design (Section 6.3), partners (Section 6.4), implementation steps (Section 6.5), operations and maintenance considerations (Section 6.6), and regulatory considerations (Section 6.7). In addition, the impact of the strategy on the environment, equity, and mobility are discussed in Section 6.8. A planning level estimation of design and implementation costs is presented in Section 6.9. Finally conclusions and recommendations for further research are discussed in Section 6.10.

6.1 FOCUS AREA DESCRIPTION

The Oakland Coliseum Focus Area is located inland of the Martin Luther King, Jr. Regional Shoreline of San Leandro Bay in Oakland, California (Figure 6-1). The area includes key transportation assets, including the I-880 Damon Slough Bridge, which is owned and maintained by Caltrans, the Oakland Coliseum BART Station and the new BART Oakland Airport Connector, and the Oakland Coliseum Capitol Corridor/Amtrak Station. The Amtrak station is owned by the city of Oakland, and operated by Amtrak staff, and the Capital Corridor Joint Powers Authority, which is fiscally affiliated with BART, operates the service side of the station. The track is owned by Union Pacific. The area also includes key commercial assets including the Oakland Coliseum Complex and the Oracle Arena, both jointly owned by the City of Oakland and Alameda County. Many agency

50 A living levee is a structure which couples multiple benefits, including flood protection and habitat restoration or creation. Typical flood protection levees do not incorporate "living" vegetated elements whereas a living levee seeks to maximize the inclusion of vegetation in order to create valuable habitats and create habitat corridors which can link critical habitat areas together. Living levees can be found in both coastal and riverine environments.

51 It should be noted, that as of December 2014, the City of Oakland has been in the process of developing a Coliseum Area Specific Plan, the goal of which is to provide the guiding framework for reinventing the City of Oakland's Coliseum area as a major center for sports, entertainment, residential mixed use, and economic growth. One of the options that may be considered under this plan is the redesign or removal of the Oakland Coliseum Complex. http://www2.oaklandnet.com/oakca1/groups/ceda/documents/policy/oak048826.pdf

Figure 6-1: Location of the focus area at the Damon Slough in San Francisco Bay (left). Close-up of the focus area (right)

stakeholders have active interests in the focus area. These include the San Francisco Bay Conservation and Development Commission (BCDC) and the Metropolitan Transportation Commission (MTC), which is the planning and financing agency in the region. Both BCDC and MTC are coordinating conservation, planning, and development efforts in the study area.

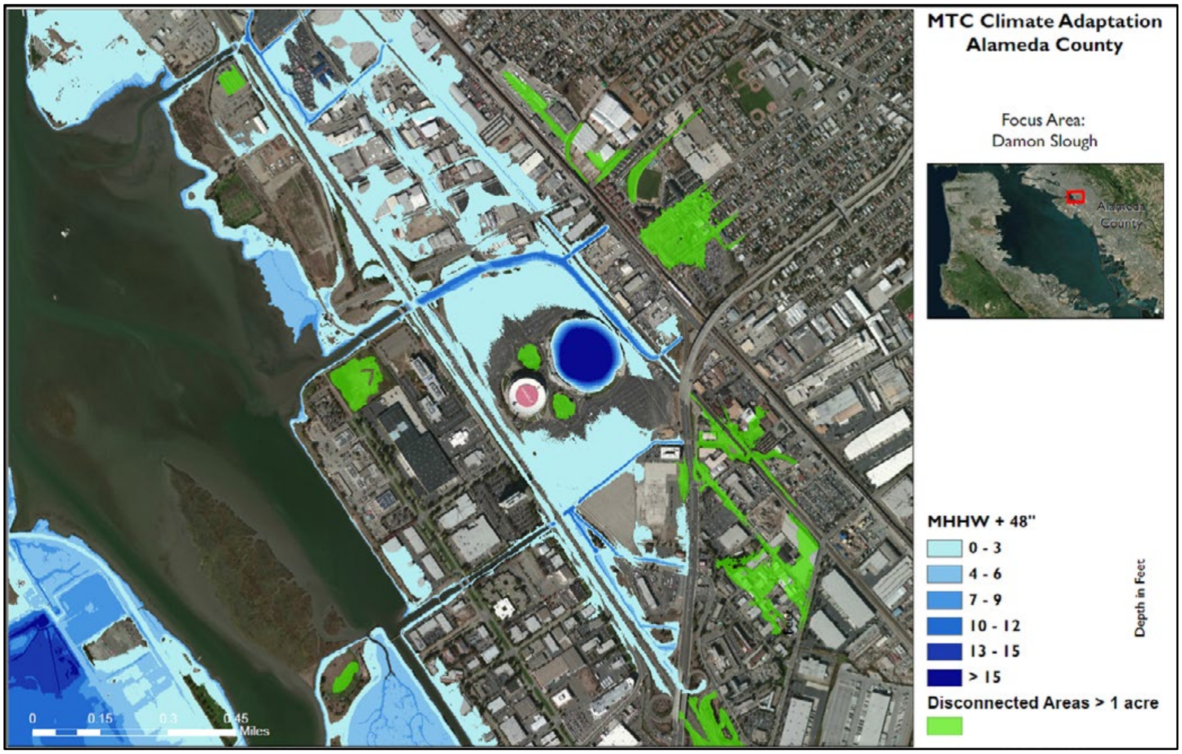
The shoreline is characterized by intermittent salt marshes and mudflats; rip-rap installed for shoreline protection, and vegetated banks. Damon Slough runs adjacent to the Oakland Coliseum and drains directly into San Leandro Bay. The slough is fed by its upstream tributaries Arroyo Viejo Creek and Lion Creek which have large urbanized watersheds. Previous inundation mapping analyses (AECOM 2014) showed that the I-880 Damon Slough Bridge and the Oakland Coliseum Complex, including the facilities and parking lot, are expected to be permanently inundated by 48 inches of SLR above mean higher high water (MHHW[52]) (Figure 6-2). This corresponds to a water level 10.6 ft. NAVD88[53]. Permanent *inundation* occurs when an area is exposed to regular daily tidal inundation. A permanently inundated area can no longer be used in the same way as an inland area due to the frequency of its exposure to sea water.

In addition to assessing permanent inundation, AECOM (2014) also evaluated the combined effects of SLR and temporary flooding from extreme tide events and extreme flow riverine events in Damon Slough. Combinations of extreme tide levels were paired with peak riverine flow rates that could be expected during coincident events. The combinations of these events were used to identify vulnerable areas and evaluate the timing of inundation or flooding during existing and future conditions. *Flooding* occurs when an area is exposed to episodic, short duration, extreme tide events of greater magnitude than normal tide levels. Inland areas may be temporarily flooded during an extreme tidal event while maintaining at least a portion of their functionality once the floodwaters recede. However, sensitive assets may suffer irreversible damage if exposed to any amount of water, even temporarily. It should be noted that AECOM's assessment of extreme tide events accounted for storm surge, and therefore represented the still water level (SWL), but did not account for wave effects. This analysis indicated that the same areas

52 Mean Higher High Water (MHHW) is used as a surrogate for the average daily high tide. MHHW is the average of the higher high water level of each tidal day observed over the National Tidal Datum Epoch. It should be noted that the actual higher high tide that occurs on any given day will be higher or lower than MHHW. MHHW is approximately 6.6 ft. NAVD88 within this focus area.

53 North American Vertical Datum of 1988. NAVD88 is a vertical control datum of orthometric height established in 1988. It is widely used in land surveying.

Figure 6-2: The expected inundation of the focus area with 48 inches of SLR (MHHW + 48 inches), which is equivalent to 10.6 ft. NAVD88



shown in Figure 6-2 would be vulnerable to flooding under the following scenarios (all approximately equivalent to a water level of 10.6 ft. NAVD88):

- 12 inches of SLR coupled with 10-year extreme tide and 10-year peak flow riverine events
- 12 inches of SLR coupled with 100-year extreme tide
- 24 inches of SLR coupled with 10-year extreme tide and 10-year peak flow riverine event
- 24 inches of SLR coupled with 100-year extreme tide and 10-year peak flow riverine event

Additional details on the inundation and flooding analysis, along with the potential impacts to assets in this focus area are presented in the Oakland-Coliseum Focus Area Technical Memorandum (AECOM 2014), which can be found in Appendix B. This assessment did not quantify the joint probability of coastal and riverine flooding; however, during moderate and strong El Nino winters, elevated storm surge water levels coupled with intense rainfall and riverine flooding is not uncommon throughout the Bay Area.

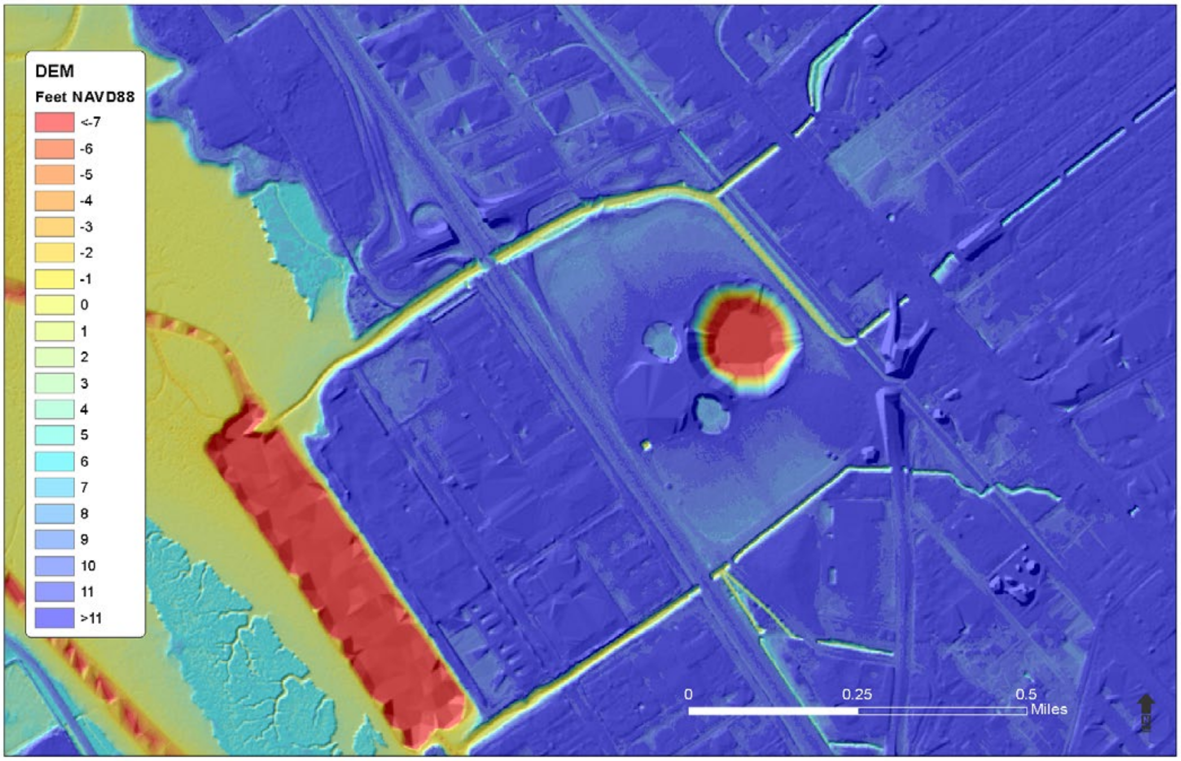
6.2 DEVELOPMENT OF DESIGN CRITERIA

Several data sets were leveraged for this study to develop design criteria for the Damon Slough living levee. The bathymetric and topographic data are described in Section 6.2.1, and the tide data and SLR scenarios are described in Section 6.2.2.

6.2.1 BATHYMETRIC AND TOPOGRAPHIC DATA

Bathymetric and topographic data were used to determine elevations at each site in the focus area and develop the conceptual designs. AECOM leveraged a merged bathymetric/topographic Digital Elevation Model (DEM) with 5 ft.-horizontal resolution for this study (Figure 6-3). The topographic portion of the DEM was built from airborne topographic light detection and ranging (LiDAR) data collected and

Figure 6-3: Image of the 5 ft. Horizontal Resolution DEM of the Focus Area



processed by the United States Geological Survey (USGS) in 2010. The bathymetric portion of the DEM was built from hydrographic sonar data collected and processed by the California Seafloor Mapping Project (CSMP) from 2004-2009. The DEM was projected horizontally in California State Plane III coordinates, referenced to the North American Datum of 1983 (NAD1983) and vertically in NAVD88. The DEM was initially developed for the Federal Emergency Management Agency (FEMA) San Francisco Bay Area Coastal Study [54] (BakerAECOM 2013).

6.2.2 TIDE AND SEA LEVEL RISE DATA AND ANALYSIS

Consideration of future sea level rise and extreme tide levels were used in the conceptual design of the living levee. To determine the overall height of the structure a range of still water levels (SWL) were considered, including current, mid-century sea level rise (e.g., low NRC estimate of 12 inches of sea level rise), end-of-century sea level rise (e.g., high estimate of 66 inches of sea level rise) and 100-year SWL. The current estimate of the 100-year SWL used in the conceptual design was MHHW + 41 inches (10 ft NAVD88) (Bay Farm Focus Area Technical Memorandum, AECOM 2014). The baseline scenario for this focus area was slightly higher than the 100-year SWL, MHHW + 48 inches, because significant inundation of critical assets occurs at this level. The height of the living levee conceptual design was selected so that it would meet the FEMA levee height accreditation criteria, and also meet BCDC's climate change policies that require larger shoreline projects be resilient to mid-century sea level rise conditions, and be capable of being adaptively managed to end of century conditions. To meet FEMA levee height criteria, the levee crest elevation needs to include 2 ft of freeboard above the 100-year SWL. Under existing conditions, this would require a levee design height of 12 ft NAVD88; under mid-century conditions with 12 inches of SLR, a levee design height of 13 ft NAVD88 would be required.

The magnitude of sea level rise that would result in permanent inundation within the focus area (as determined by the project's inundation mapping analysis) was also considered. The Oakland Coliseum

54 www.r9coastal.org

Complex and I-880 Damon Slough Bridge are expected to be permanently inundated with a minimum of 48 inches (4 feet) of SLR at MHHW (AECOM 2014). The current MHHW water level for the focus area was derived from the MIKE21 model output (DHI 2011). The MHHW tidal datum was calculated using the portion of the model output time series corresponding to the most recent National Tidal Datum Epoch (1983 through 2001), which is a specific 19-year period adopted by NOAA to compute tidal datums. The current MHHW water level for this area was calculated to be 6.6 ft. NAVD88. The sum of the MHHW water level (6.6 ft. NAVD88) and a sea level rise magnitude of 4 feet is 10.6 ft. NAVD88. This total water level could also be reached under the combined scenarios of sea level rise, extreme tide events, and peak flow riverine events listed in Section 6.1. The levee design height of 13 ft NAVD88 is therefore high enough to protect the area from permanent inundation with 48 inches of sea level rise.

6.3 CONCEPTUAL DESIGNS

Different types of flood protection structures were considered to provide protection from SLR and storm surge to assets in the Coliseum Focus Area, including a traditional levee and a living levee. A living levee was determined to be the preferred potential adaptation strategy of choice over a traditional levee after weighing the pros and cons of both options. Traditional levees typically have relatively steep slopes and a narrow footprint, while living levees typically have a flatter waterside slope and a wider footprint (USACE 1994; CDWR 2012). A traditional levee with steeper slopes can be designed and potentially constrained within the existing banks of the slough, whereas a living levee cannot be constrained within existing banks, and would likely encroach into the Coliseum parking lot area. However, the flatter waterside slope of a living levee can enable the creation of marsh and riparian habitat, and provide a broad floodplain that could accommodate higher flows. A broad floodplain would relieve the pressure exerted by water flows and reduce scour on the numerous crossings that go over Damon Slough (I-880, Coliseum Way, and railroad tracks). Furthermore, a living levee can enhance the natural aesthetics of the slough. Because of its larger cross-sectional area, the living levee will also have sufficient accommodation space to allow for future adaptive management that could be needed to address SLR in the future. Finally, a living levee might be a better fit for this focus area because it would have a flatter slope compared to that of a traditional levee, and this would address the height constraints posed by the numerous low crossings that go over Damon Slough.

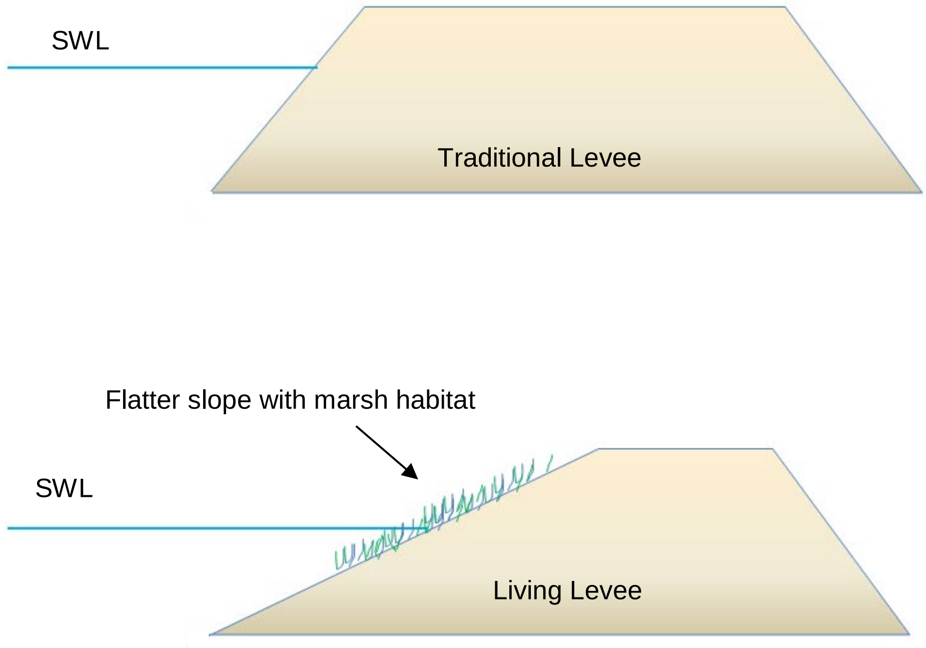
6.3.1 CONCEPTUAL DESIGN OF THE LIVING LEVEE

Using data and design conditions described in previous sections, AECOM developed a conceptual design for a living levee along Damon Slough, following guidance developed by the US Army Corps of Engineers (USACE) and the California Department of Water Resources (CDWR).

The living levee conceptual design presented includes only a levee design with integrated habitat elements (see Figure 6-4). However, the conceptual design could be expanded to include public access and recreation elements, a broader floodplain, or additional wetland or upland transition habitats. Furthermore, in areas where the living levee footprint encroaches on a critical asset that cannot be impacted, a segment of traditional levee with a smaller footprint can be constructed. Segments of a traditional levee could be constructed on the north side of the channel where space is limited.

Using data and design conditions described in the previous section, AECOM developed a conceptual design for a living levee along Damon Slough, following guidance developed by the US Army Corps of Engineers (USACE) and the California Department of Water Resources (CDWR). To develop a conceptual design for the living levee, several cross sections along the channel were extracted from the DEM to design the living levee dimensions. The cross sections are nearly identical along the channel and one cross section east of the Oakland Coliseum Complex was selected for the conceptual design. For FEMA accreditation the crest elevation of the living levee must be a minimum of 2 feet above the 100-

Figure 6-4: Conceptual diagrams of a traditional levee (top) and living levee (bottom)



year extreme tide elevation (i.e., 100-year SWL[55]). This is equivalent to 41 inches (equal to 3.4 feet) above the MHHW level (6.2 feet), which amounts to approximately 10.0 ft. NAVD88. Additionally, because Damon Slough exhibits both coastal and riverine flooding, the crest elevation must also be a minimum of 2 feet above the water surface elevation associated with a riverine 100-year peak flow event. The higher of the two elevations would govern the overall design criteria. For this conceptual design analysis, the living levee crest elevation is assumed to be 2 feet higher than the sum of the MHHW level of 6.2 feet and a sea level rise magnitude of 48 inches (4 feet), amounting to a total of 12.6 ft. NAVD88.

The design slope of the living levee on the landward side is the maximum recommended 2:1 (H:V) and the crest width is the minimum recommended 10 feet (USACE 1994; CDWR 2012). The waterside slope is a much flatter 5:1 (H:V) to accommodate intertidal marsh and upland habitat. For conceptual design and cost estimate purposes, the living levee design is assumed to encroach into the Coliseum parking lot area by approximately 30 feet[56]. If space allows, the living levee can be constructed with a wider footprint to increase the marsh habitat and floodplain. Figure 6-5 shows the approximate layout and footprint of the conceptual design of the living levee along Damon Slough. Figure 6-6 shows a cross-section of the conceptual design on the representative profile.

Sufficient space may not be available to install a living levee along the entire length of Damon Slough. The levee is designed to protect I-880 indirectly by preventing water from flooding over the channel banks, into the parking lot, and onto I-880. However, the bridge crossings associated with I-880 and Coliseum Way may constrain the living levee design and bridge considerations will need to be explored in greater depth during the preliminary design phase. In this area, segments of a narrower traditional levee could be constructed if space permits. In addition, immediately east of the Coliseum there is limited space for a living levee, or a traditional levee, due to the need to maintain the access road adjacent to the

55 The 100-year still water level (SWL) is the coastal SWL that has a 1 percent chance of occurring in any given year, in the absence of wave effects. When wave affects are included, the reference water level is commonly referred to as the total water level (TWL). In the protected environment of San Leandro Bay and Damon Slough, wave effects can largely be neglected.

56 A more traditional levee could be designed that minimizes encroachment into the Coliseum parking lot, but a traditional levee would not include integrated habitat elements. In areas where the living levee encroaches on assets that cannot be impacted, segments of a narrower traditional levee can be constructed.

Figure 6-5: The layout and footprint of the living levee (brown) and the section where seawall might be necessary due to space limitations

Coliseum for maintenance/service vehicles. In this area, placement of a seawall is recommended for providing flood protection from both coastal and riverine flood sources as needed. However, if the Coliseum Complex is redesigned or removed (which may be one alternative under the Coliseum Area Specific Plan[57]), a living levee design for this reach would likely be possible. If a wider floodplain with additional living levee setbacks could be established in this area (i.e., encroaching more into the existing Coliseum parking lot areas), this could provide additional flood conveyance and flood storage capacities, potentially delaying the need to modify and raise bridge connections and overpasses within this focus area.

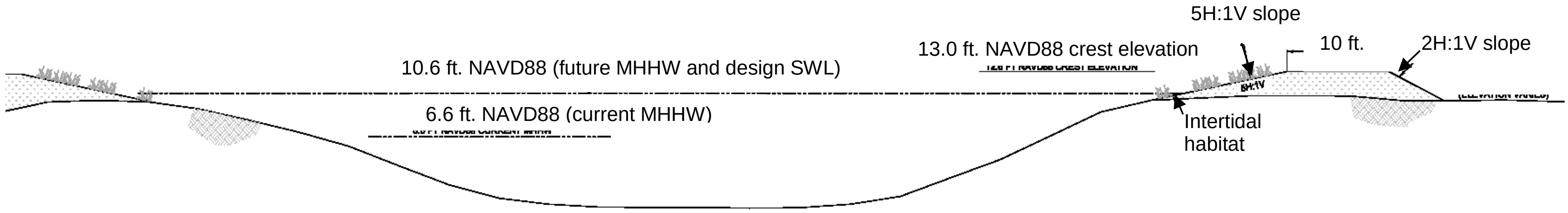
It is important to note that in areas where the living levee footprint encroaches on a critical asset that cannot be impacted, a segment of traditional levee with a smaller footprint can be constructed.

6.4 PARTNERS

The strategy described in this section cannot be successfully designed and implemented without the collaboration of relevant local, regional, State, and federal agencies. Such agencies include Caltrans (which owns and manages the I-880 over Damon Slough), the Oakland-Alameda County Coliseum Authority (established jointly by the City of Oakland and Alameda County to manage the Coliseum Complex), BCDC, San Francisco Bay RWQCB, CDFG, California SLC, NOAA, USACE, Capitol Corridor and BART. The respective roles of these agencies in designing and implementing these strategies are described in Sections 6.5 and 6.7.

57 See: http://www.oaklandnet.com/coliseumcity/

Figure 6-6: A conceptual cross-section of the Damon Slough living levee. The living levee is designed to protect against flooding and inundation associated with water levels up to 13 ft. NAVD88 and provide intertidal and upland habitat zones



6.5 IMPLEMENTATION STEPS

This section details the steps to implementing the living levee strategy. The full list of adaptation strategies developed in the in the initial stages of this study (see Compendium of Strategies in Appendix C for more information) should be reviewed in case a more appropriate strategy can be implemented. Given that this strategy requires collaboration among multiple agencies (listed in Section 6.4) and involves large-scale construction near the Bay (which, in turn, can trigger complex environmental/regulatory requirements), the implementation of this strategy could potentially be significantly more time- and cost-intensive, compared to more traditional transportation projects. As a first step in the implementation process, there should be convening and coordination among all critical stakeholders. These include Caltrans, which owns and maintains the I-880 Damon Slough Bridge, and the City of Oakland and Alameda County, which jointly own the Oakland Coliseum Complex and Oracle Arena properties. BART and Capitol Corridor should also be involved as the living levee may impact their properties on the east side of the focus area. Once concerns are addressed from the stakeholders and if it is decided to move forward with a living levee, a preliminary Environmental Assessment should be conducted to investigate environmental effects. It is important to note that construction of the living levee will impact the existing marshes and shoreline. However, the living levee will positively affect the natural environment as well. The living levee will create significant new shoreline habitat. It will be critical that the construction of the living levee follows the requirements set forth in the National Environmental Policy Act (NEPA) and the California Environmental Quality Act (CEQA). The structures will need approval by USACE as well as BCDC, as both agencies regulate the placement of material for Bay protection structures through their permitting process. BCDC must also determine that the fill associated with the project is the minimum necessary and that no upland alternative exists, although this structure is technically located away from the Bay.

Once all permits are obtained, detailed topographic surveys should be conducted. This will refine the elevation data and allow for more detailed engineering design of the living levee. Particular attention should be paid to the space restrictions near the I-880 bridge crossing and east side of the Stadium. Geotechnical surveys should be conducted at both sites to provide greater detail on the sediment and soil conditions. This information is required to design against potential settlement, subsidence, and degradation of the structures. After the surveys, detailed engineering drawings would be developed to guide construction. In areas where space is limited, such as the I-880 bridge crossing, segments of a more traditional levee with a narrower footprint can be designed. A seawall will most likely be required on the east side of the stadium where there is little space. A subsequent construction survey will mark key construction benchmarks at the site. After these steps, the construction phase can begin.

6.6 OPERATIONS AND MAINTENANCE CONSIDERATIONS

AECOM has completed an overview of the expected operations and maintenance activities for the living levee and sea wall. Expected operations and maintenance activities for the living levee and sea wall include:

- All permits need to be current and updated as needed.
- The dirt trail on top of the living levee (adjacent to the Coliseum parking lot) needs to be maintained and in operable condition. Eroded or subsided sections need to be fixed to maintain access.
- The living levee needs to be routinely inspected for damage and/or deterioration.
- Sections of the living levee that deteriorate due to scour from peak flow-induced erosion or seepage need to be fixed to maintain protection from inundation and flooding.

- Sections of the living levee that subside may need to be built higher to maintain protection from inundation and flooding.
- For higher SLR scenarios, localized areas of the living levee may need to be built to higher elevations to maintain protection from flooding.
- Vegetation may need to be planted in areas where habitat is degraded.
- Regular inspections of the seawall and adjacent areas may be required for safety and crime prevention. If persistent problems occur, these areas may require video monitoring or surveillance for security.

6.7 REGULATORY CONSIDERATIONS

The implementation of this adaptation strategy will incorporate several different planning and development activities, including Bay and riverine flood protection, and shoreline and riverine habitat restoration. In addition, many agencies may exercise regulatory control over this focus area. Therefore, there are unique regulatory criteria for this project. The following is a list of agencies that will require consultations and/or regulatory permits:

- USACE Section 404/10 permit for construction
- NOAA Fisheries (formerly NMFS) Magnuson-Stevens Fishery Conservation and Management Act consultation
- NOAA Fisheries and US Fish and Wildlife Service Endangered Species Act (ESA) Section 10 consultation
- CA Department of Fish and Game (CDFG) California Endangered Species Act (CESA) consultation
- BCDC compliance with the McAteer-Petris Act that promotes responsible planning and to eliminate unnecessary placement of fill (i.e., upland alternative analysis, minimum fill necessary)
- BCDC administration of the Coastal Zone Management Act (CZMA)
- California State Lands Commission (SLC) for Aquatic Lands Lease if located on state aquatic lands
- San Francisco Bay Regional Water Quality Board (RWQCB) Clean Water Act (CWA) 401 Water Quality Certification
- RWQCB Porter-Cologne Water Quality Control Act – State law equivalent of the 401 Water Quality Certification
- Alameda County “Land Use Permit” --- More research needed to identify these details
- Alameda County “Flood Plain/Flood Control” --- More research needed to identify these details
- Bay Area Air Quality Management District Engine Permit – Required for heavy diesel powered equipment. This may or may not be applicable.
- Caltrans for any work on the bridge which will require an encroachment permit.

6.8 IMPACT ON ENVIRONMENT, EQUITY, AND MOBILITY

6.8.1 IMPACTS ON ENVIRONMENT

The environmental benefits of this strategy were evaluated by estimating the acres of wetlands within the Coliseum Focus Area boundaries that are expected to be protected from the magnitude of permanent inundation or temporary flooding expected under the baseline scenario for the Coliseum Focus Area

(MHHW + 48-inch SLR) as a result of the implementation of this strategy. As a first step, the total land area expected to be protected by the installation of a living levee on either side of Damon Slough was estimated on the basis of factors such as living levee placement, the extent of flooding projected under the baseline scenario for the Coliseum Focus Area, and drainage patterns for Damon Slough as well as other creeks in the region, such as Lion Creek, San Leandro Creek, and East Creek Slough.

It was assumed that the living levee can likely prevent flooding which would otherwise be caused by overflows from Damon Slough, but will not prevent flooding caused by overflows from other creeks. Within the total land area likely to be protected, the acres of existing wetlands were identified using GIS data compiled by the Bay Area Aquatic Resources Inventory (BAARI). This analysis estimates that approximately 9 acres of wetlands along Damon Slough could be protected from flooding as a result of the implementation of this strategy. Most of this acreage is characterized as 'Tidal Channel Flat' wetlands in the BAARI database. This analysis does not take into consideration additional wetlands or habitat that may be created as a result of the living levee. It should also be noted that this analysis does not consider how wetland or habitat areas will change as and when this focus area system finds equilibrium in response to the proposed strategy.

6.8.2 IMPACTS ON EQUITY

The social benefits of this strategy were evaluated by estimating the population and number of jobs within the Coliseum Focus Area boundaries that are expected to be protected from the magnitude of permanent inundation or temporary flooding expected under the baseline scenario for the Coliseum Focus Area (MHHW + 48-inch SLR) as a result of the implementation of this strategy. As a first step, the total land area expected to be protected by the installation of a living levee on either side of Damon Slough was estimated on the basis of factors such as living levee placement, the extent of flooding projected under the baseline scenario for the Coliseum Focus Area, and drainage patterns for Damon Slough as well as other creeks in the region, such as Lion Creek, San Leandro Creek, and East Creek Slough. It was assumed that the living levee can likely prevent flooding which would otherwise be caused by overflows from Damon Slough, but will not prevent flooding caused by overflows from other creeks.

The land area expected to be protected by this strategy includes most of the Coliseum Complex along with a cluster of commercial or industrial parcels bordered by Independent Road and 66th Avenue in the North and South respectively, and by the Amtrak rail tracks and I-880 in the East and West respectively. Within the total land area likely to be protected, the number of protected residents and jobs was estimated using GIS data provided by the Metropolitan Transportation Commission (MTC) on population and employment projections under Plan Bay Area's "Preferred Scenario"[58] for the year 2040. This analysis estimates that approximately 800 jobs could be protected from flooding as a result of the implementation of this strategy. With regard to the estimates of protected population, it was found that the land area likely to be protected does not include any residential zones. Therefore, the social benefit analysis for residents is not applicable to this strategy.

6.8.3 IMPACTS ON MOBILITY

This strategy could potentially prevent adverse impacts on mobility from disruptions in operations in both transit and roadway systems, which would otherwise occur under the baseline scenario for the Coliseum Focus Area (MHHH + 48-inch of SLR).

[58] The "Preferred Scenario" is a planning scenario for the Bay Area's Sustainable Communities Strategy (SCS) and Regional Transportation Plan (RTP) that articulates the Bay Area's vision of future land uses and transportation investments, against which the region's performance relative to statutory greenhouse gas and other voluntary performance targets are measured.

The following adverse impacts are expected to occur under the baseline scenario in the absence of the implementation of this strategy. A description of the methodology used to quantify each of these impacts is provided in Table 6-1 under Chapter 4, Section 4.4.1.

Table 6-1: Impacts prevented through implementation of strategy

AVOIDED IMPACT	DAILY CHANGE (PERCENTAGE CHANGE)	AVOIDED DAILY COST ($)*
Decrease in transit ridership (BART average weekday boardings disrupted from damage to station access)	-7,100 (-100%)	Not available
Decrease in transit ridership (BART average weekday system-wide boardings disrupted from damage to traction power and station access)	-84,842 (-100%)	Not available
Increase in vehicle miles traveled (passenger vehicles)	+216,670 (+0.15%)	$100,337
Decrease in vehicle miles traveled (trucks)	-9,221 (-0.06%)**	
Increase in vehicle hours traveled (passenger vehicles)	+31,303 (+1%)	$391,288
Increase in vehicle hours traveled (trucks)	+3,160 (+1%)	$90,692
Increase in vehicle hours of delay (passenger vehicles)	+22,484 (+7%)	Not available
Increase in vehicle hours of delay (trucks)	+2,167 (+8%)	Not available
Number of # of transit routes impacted in or within ½ mile of communities of concern (AC Transit local routes)	9	None
Number of # of transit routes impacted in or within ½ mile of communities of concern (AC Transit transbay routes)	2	None
Increase in GHG emissions from all on-road vehicles (tons per day)	+110,558 (+0.3%)	$2,542,834
Change in Criteria Air Pollutant emissions (tons per day)	See below	
ROG	+30.3 (+0.22%)	None
NOx (Summertime)	-47.8 (-0.06%)***	-$826,940
CO	+241.7 (+0.32%)	$18,128
PM_{10}	+41.1 (+0.26%)	$5,749,890[59]
$PM_{2.5}$	+9.9 (+0.23%)	None
NOx (Wintertime)	-52.9 (-0.03%)***	None
Total Estimated Daily Avoided Costs to the Region		**~$8.1 Million**

* Cost valuations are rounded to the nearest $100,000 and are based on Caltrans' Life-Cycle Benefit-Cost Analysis Economic Parameters (2012)[60], as applicable (in 2012 dollars). VMT costs include vehicle operating expenses assessed directly to vehicle owners (fuel and wear & tear expenses). Emissions costs reflect "health costs" to the public (such as costs of hospitalizations, disease, and mortality). Fuel economy estimates are for 2011 fleet[61].
**The estimated decrease in truck VMT is due to reduced truck trips resulting from closed roadway systems as a result of permanent inundation and/or temporary flooding in the Coliseum Focus Area.
***The estimated decrease in NOx emissions is directly correlated to the estimated decrease in truck VMT.

As a result of the implementation of this strategy, disruptions to boardings at the Coliseum BART station could be prevented. In addition, system-wide disruptions to BART ridership from damage to traction power and lack of station access could also be prevented. Furthermore, disruptions to local and trans-bay transit routes in or within ½ mile of communities of concern (CC) could be prevented. In the case of roadway systems, the aforementioned increases in vehicle miles traveled, vehicle hours traveled, and vehicle hours of delay could be prevented. In turn, the increase in GHG and criteria air pollutant emissions, which is directly related to vehicle miles traveled, is expected to be prevented. In the case of commercial trucks, it should be noted that the truck vehicle miles travelled are actually expected to

59 The PM_{10} cost estimate reflects the value assigned by Caltrans to PM10 in urban areas (other than LA/South Coast) of $139,900 per US ton. See: http://www.dot.ca.gov/hq/tpp/offices/eab/benefit_cost/LCBCA-economic_parameters.html
60 See: http://www.dot.ca.gov/hq/tpp/offices/eab/benefit_cost/LCBCA-economic_parameters.html
61 See: http://www.eia.gov/totalenergy/data/monthly/pdf/sec1_17.pdf

decrease under the baseline scenario, in the absence of this strategy[62]. This estimated decrease in truck VMT is directly linked to the estimated decrease in one of the criteria air pollutants evaluated in this analysis (NOx). The decrease in truck VMT is characterized as an adverse impact in this analysis even though it contributes to lower GHG and NOx emissions from trucks, because it is an indicator of disruption to economic activity in the region. Implementation of this strategy could prevent disruption to truck trips in the region.

6.9 PLANNING LEVEL COST ESTIMATION

AECOM has developed conceptual-level cost estimates for the implementation of this strategy based on similar projects constructed in similar environments. The costs for the living levee are detailed in and include the units, quantities, unit prices, and item prices. Important items in the costing estimate include initial topographic and geotechnical surveys which are required to refine the design to construction specifications. They also include subsequent clearing and demolition/disposal which will be necessary to prepare the site. Costs of construction of the living levee and dirt trail are included. Finally, costs associated with the placement of habitat sediments and vegetation plantings are detailed. It is important to note that this appears to be relatively simple construction with limited complexity so a 20-30% concept level contingency could be considered typical. However, there are high levels of uncertainty associated with the site conditions, design and construction criteria and constraints, permit/regulatory requirements, and some item costs. To account for these uncertainties a slightly higher contingency of 40% is used in Item 14. The total estimated project cost is approximately $2.9 Million. Costs for obtaining permits will not be included in the estimate, nor the cost of carrying out the necessary CEQA/NEPA reviews. Design costs are included in Item 12. It is important to note that the cost per linear foot is lower for these levees compared to the Bay Bridge levee. This is because they have a much smaller cross-sectional area (i.e., they are much shorter and narrower) than the Bay Bridge levee and can be built with much less material.

6.10 CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

There are many types of potential adaptation strategies that could be implemented to protect against SLR and storm surge in this focus area. AECOM developed a conceptual living levee design that will potentially protect the focus area from inundation and flooding associated with future SLR, extreme tide events, and riverine peak flow events. The living levee will also provide intertidal and upland habitat zones which will increase the natural aesthetics of the area. The living levee might be a more appropriate fit for areas along the slough that have vertical height constraints, and will increase the channel width for peak-flow riverine events, and provide room for future design changes. There is insufficient space for a living or traditional levee immediately east of the Coliseum and a seawall could be constructed here to provide the desired level of flood protection. In other areas where the living levee footprint encroaches on assets that cannot be impacted, a narrower, traditional levee can be constructed.

Additional details will be required before the conceptual levee design presented in this section can be elevated to the design process. Most notably, the living levee design under and adjacent to the I-880 and Coliseum Way bridge crossings will require additional analysis, and the bridge designs and foundations must be investigated so that the living levee does not impact these. Furthermore, the conceptual design presented currently only addresses flooding concerns within and adjacent to Damon Slough; however,

[62] Truck miles are reduced because key links within the truck Origin and Destination TAZs are inundated, and therefore those truck trips cannot load onto the network (i.e., they are "lost" trips). As a result, overall truck VMT falls, despite the fact that the truck trips which do take place are likely to be longer.

Table 6-2: Conceptual-Level Cost Estimate for the Living Levee

	Item	Units	Quantity	Unit Price	Item Price
1	Project Mobilization/Demobilization (10% of base construction cost)	%	10		$142,360
2	Demolition/Disposal, Clearing/Rough Grading	LS	1	$180,000	$180,000
3	Signage and Traffic Control	LS	1	$20,000	$20,000
4	Survey	LS	1	$25,000	$25,000
5	Levee Construction	LF	7,000	$130	$910,000
6	Pedestrian Bike Path	SY	4,600	$14	$64,400
7	Pavement (including curb, gutter, stormwater) Replacement/Construction	SY	1,900	$70	$133,000
8	Plantings (in Place)	SY	11,400	$8	$91,200
9	**Sub-Total 1: Estimated Base Construction Cost:**				**$1,565,960**
10	Sales Tax @ 8.75% of Base Construction Cost				$137,022
11	**Sub-Total 2: Estimated Base Bid:**				**$1,702,982**
12	Permitting and Design (12% of base construction cost)	%	12		$187,915
13	Bidding/Contract Admin/Construction Oversight (10% of base construction cost)	%	10		$156,596
14	Concept Level Contingency (40% of Project Costs)	%	40		$818,997
15	**Total Estimated Project Cost:**				**~$2.9M***

*The total estimated projected cost has been rounded to the nearest $100,000

modeling conducted by AECOM noted that additional flooding concerns are associated with the upstream tributaries. Additional modeling and analysis of Damon Slough and its upstream tributaries would need to be completed before proceeding with preliminary design.

6.11 REFERENCES

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Adaptation Strategy: State Route 92 Drainage Study

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7. ADAPTATION STRATEGY: STATE ROUTE 92 DRAINAGE STUDY

This section presents a scope for conducting a comprehensive drainage assessment in the San Mateo – Hayward Bridge (SR 92) touchdown area. The westbound lanes within the touchdown area are expected to be permanently inundated under a sea level rise (SLR) scenario of 48 inches, but the effectiveness of the drainage system along SR 92 may be compromised with only 24 inches of SLR. Detailed inundation mapping and a review of the critical inundation pathways within the Hayward Focus area supported the development of several physical adaptation strategies that could protect the highway and adjacent areas from future coastal inundation and flooding. However, the Hayward Focus Area is complex, and the drainage pathways and the inter-relationship between the highway drainage systems and the surrounding areas are not well understood. Any physical adaptation strategies proposed for this area must consider the existing highway drainage system, and allow provisions for future highway drainage in a responsible and practical manner – including considerations for maintaining the drainage system as sea levels rise.

An understanding of the drainage network, and how the capacity and performance of the drainage network will change with sea level rise, is the logical next step in both understanding the vulnerabilities in this area, and developing adaptation strategies that can address both sea level rise and precipitation-based flooding. Addressing this informational vulnerability will be the key to unlocking future action, including developing effective strategies that address the physical and functional vulnerabilities.

This scope provides a roadmap for completing a drainage assessment of the SR 92 area and the adjacent areas. Section 7.1 provides an overview of the SR 92 touchdown area. Section 7.2 provides descriptions of the primary scope elements. Sections 7.3, 7.4 and 7.5 describe the recommended partnerships, regulatory considerations, and impacts of this strategy on the environment, equity, and mobility. Section 7.6 provides a planning level cost estimate, respectively, for completing the study. Lastly, Section 7.7 provides a summary of the conclusions for completing the drainage study.

7.1 FOCUS AREA DESCRIPTION

The San Mateo-Hayward Bridge was originally constructed in 1929, and was the longest bridge in the world when it opened. The bridge and the touchdown areas and toll plazas have undergone several improvement and expansion projects since it was first constructed. The most recent modifications included a seismic retrofit project in 2000 and an expansion from four to six lanes in 2003 by construction of a parallel bridge structure to the east causeway section. The expansion project included improvements and widening of the eastern touchdown located within the Hayward Focus Area, between Sulphur Creek and Alameda Creek along the eastern shoreline of San Francisco Bay (Bay). The touchdown area is located between the Hayward Regional Shoreline to the north and Eden Landing Ecological Reserve to the south (See Figure 7-1). Figure 7-2 shows the Caltrans drainage structures located within the SR 92 touchdown area. Definitions of the drainage structures are provided in Section 7.2.1.

The westbound lanes of SR 92 near the bridge touchdown area are expected to be permanently inundated by 48 inches of SLR (Figure 7-3). Permanent inundation occurs when an area is exposed to regular daily tidal inundation. A permanently inundated area can no longer be used in the same way as an inland area due to the frequency of its exposure to sea water. In addition to assessing permanent inundation, AECOM (2014) also assessed the combined effects of permanent inundation and temporary flooding from extreme tide events. Temporary *flooding* occurs when an area is exposed to episodic, short duration, extreme tide events of greater magnitude than normal tide levels. Inland areas may be temporarily flooded during an extreme tidal event while maintaining at least a portion of their functionality

Figure 7-1: San Mateo-Hayward Bridge (SR 92) Touchdown Focus Area and Surrounding Watersheds[63]

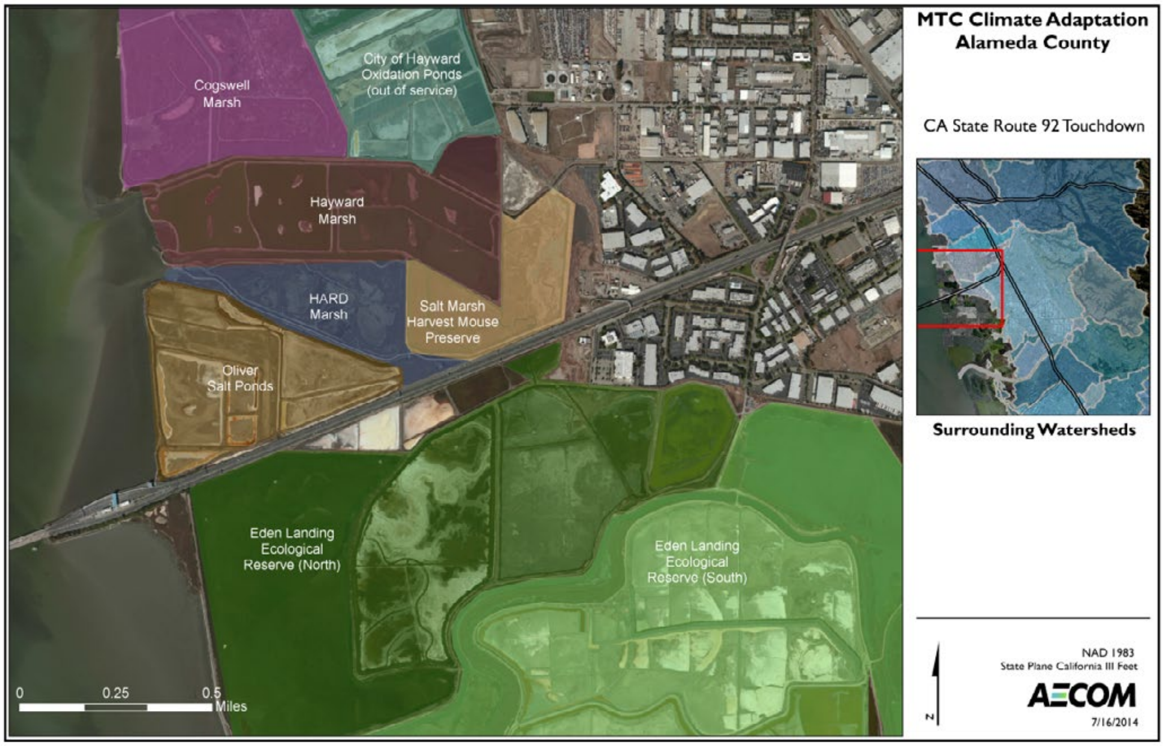
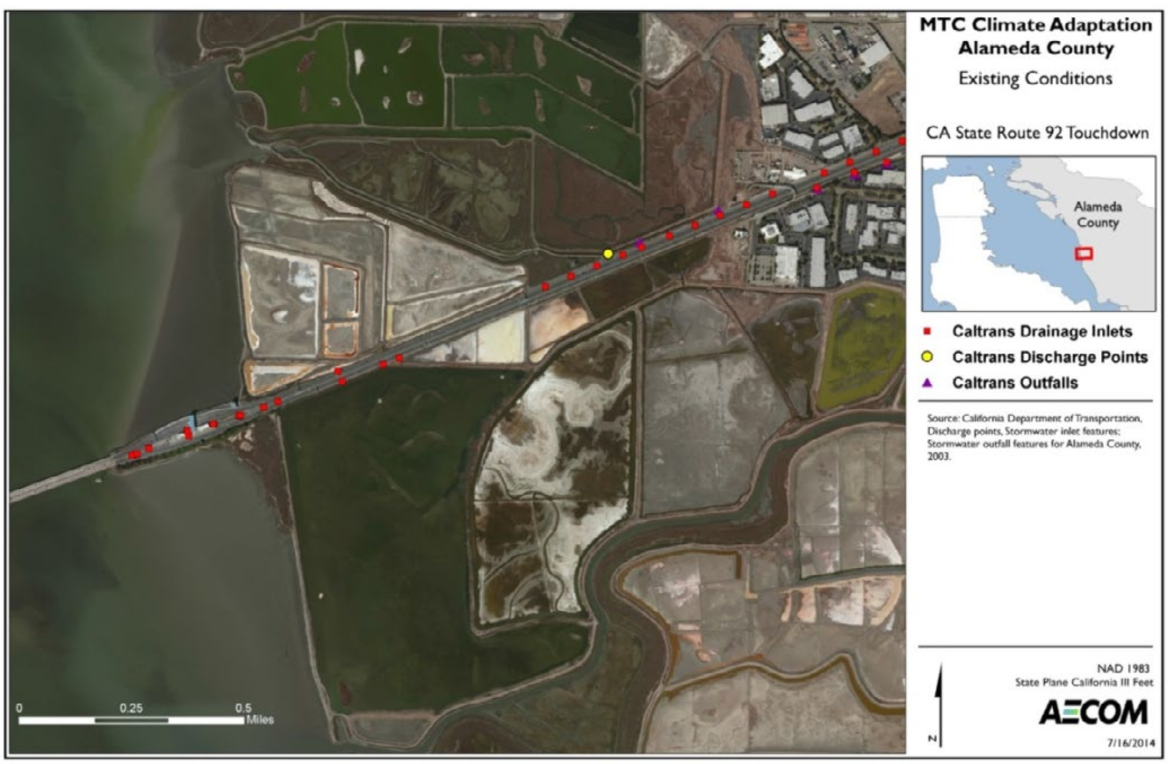


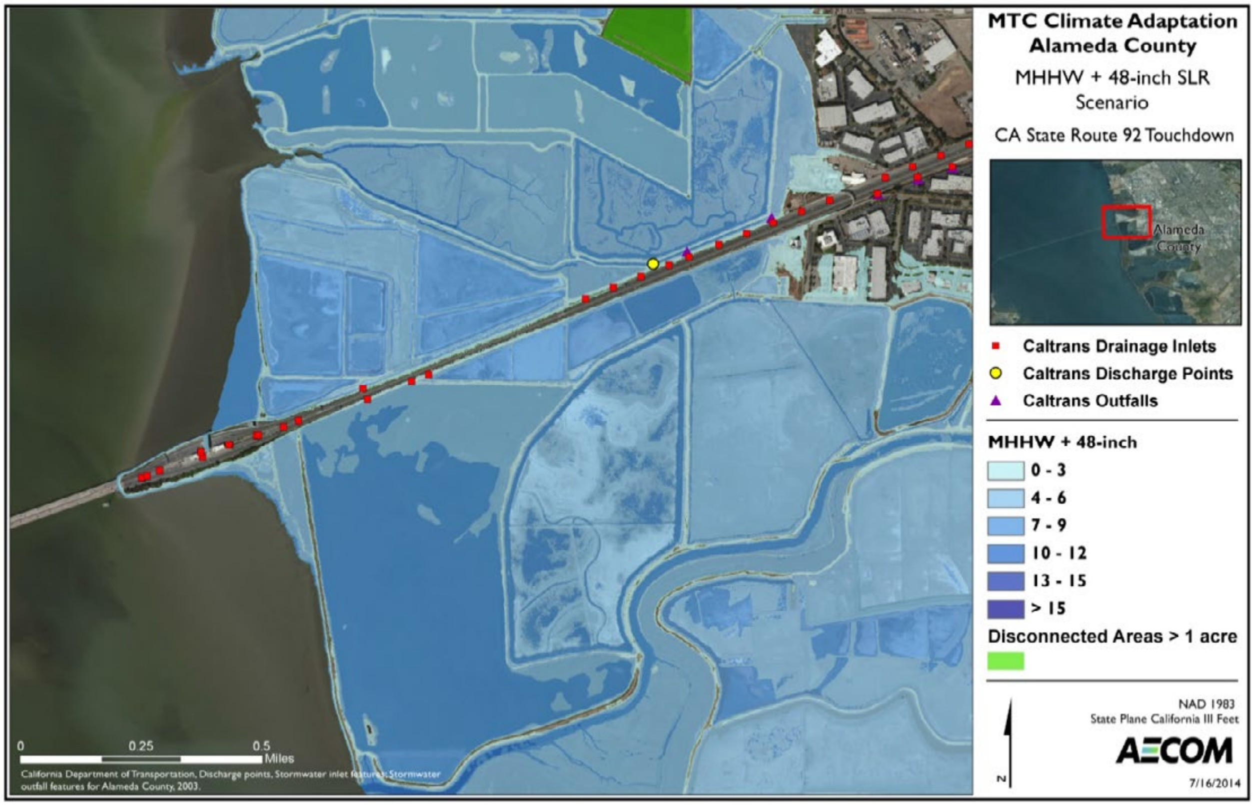
Figure 7-2: SR 92 Touchdown Caltrans Drainage Structures[64]



63 Watersheds layer source: Sowers, J.M., Richard, C., Dulberg, R. and Holmberg, J.F., 2010, Creek & watershed map of the Western Alameda County: a digital database, version 1.0: Fugro William Lettis and Associates, Inc., Walnut Creek, CA, 1:24,000 scale

64 See Section 7.2.1 For Definitions Of Caltrans Drainage Structures

Figure 7-3: Inundation at SR 92 Touchdown (MHHW + 48-inch Scenario)



once the floodwaters recede. However, sensitive assets may suffer irreversible damage if exposed to any amount of water, even temporarily. Thus, the inundation maps in this section, which show the extent of inundation from 24 inches, 36 inches, and 48 inches of SLR (Figure 7-4, Figure 7-5, and Figure 7-3 respectively), can represent both permanent daily tidal inundation and also temporary flooding from lower magnitudes of SLR combined with shorter term extreme tide events. The analysis indicates that the west bound lanes would be flooded under the following combined scenarios of SLR and extreme tide events:

- 36 inches of SLR coupled with a 1-yr tide event
- 30 inches of SLR coupled with a 2-yr tide event
- 24 inches of SLR coupled with a 5-yr tide event
- 18 inches of SLR coupled with a 25-yr tide event
- 12 inches of SLR coupled with a 50-yr tide event
- 6 inches of SLR coupled with a 100-yr tide event

The combined scenarios of SLR and extreme tide events listed above could cause the same extent of flooding of the westbound lanes as the extent of flooding caused by permanent inundation under the 48-inch SLR scenario. Additional details on the inundation and flooding analysis, including the critical pathway analysis, are presented in the Hayward Focus Area Technical Memorandum (AECOM 2014), which can be found in Appendix B.

Figure 7-4: Inundation at SR 92 Touchdown (MHHW + 24-inch Scenario)

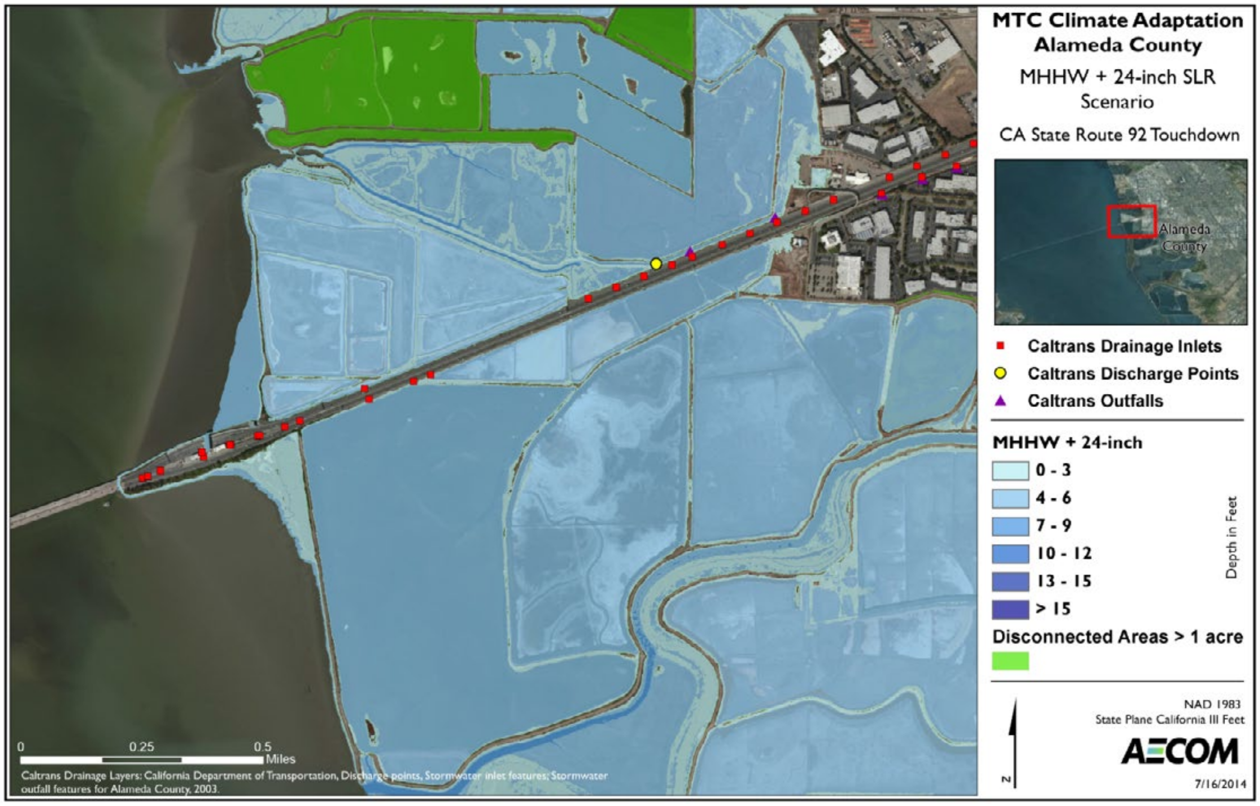
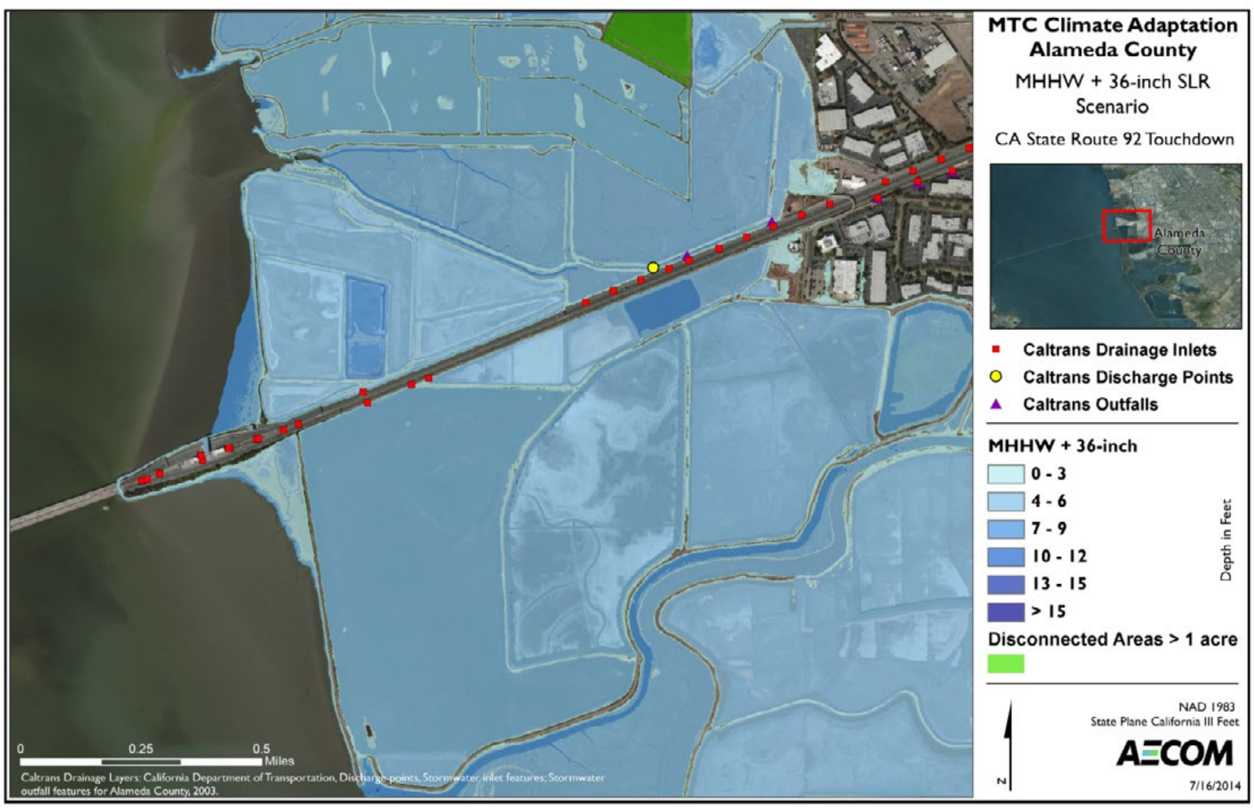


Figure 7-5: Inundation at SR 92 Touchdown (MHHW+ 36-inch Scenario)



7.2 SCOPE OF STUDY

The SR 92 drainage study scope should include the following components:

- Review and summarize existing conditions information (as it is available), including the design criteria and design storm used for the current drainage system;
- Review and documentation of existing and readily available models of the current drainage network, as well as adjacent drainage networks that may connect to the SR 92 drainage system;
- Review and documentation of the existing capacity of the current drainage system as well as the primary drainage flow paths and connections to the adjacent areas;
- Evaluation of how the capacity and needs of the drainage system will change over time with climate change – including sea level rise and potential increases in precipitation; and
- Recommendations for future conditions (e.g., design storm and sea level rise / storm surge scenarios) that should be considered as physical adaptation strategies for SR 92 are evaluated and developed.

The following sections provide descriptions of each of the above components.

7.2.1 REVIEW AND DOCUMENTATION OF EXISTING CONDITIONS

The relevant existing design documents and supporting analysis associated with the SR 92 drainage system in the vicinity of the touchdown area should be compiled and reviewed (e.g., the documents associated with the 2000 and 2003 upgrades and modifications should be available from Caltrans (Office of Hydraulic Engineering), and additional information may be available from adjacent landowners). This information will assist in enhancing the overall understanding of the existing drainage system, including the design criteria used during the original design and subsequent modifications. If practical, the age and condition of the drainage components should also be documented. The existing Caltrans drainage structures located within the focus area, including drainage inlets, discharge points, and outfalls are shown in Figure 7-2. Definitions of these drainage structures, as cited in the Caltrans Phase II Storm Drain System Inventory Field Guide (July 2009), are provided below:

- Inlets: *Inlets are locations where stormwater enters a conveyance structure (pipe or ditch), and includes drain inlets, openings in curbs or the median, and other places stormwater is collected and directed into a conveyance structure. An inlet is a drainage entryway for water to enter into the storm drain and is often covered by a metal grate or constructed of a slotted pipe*.
- Discharge Points: *Discharge points are the points at which stormwater flow leaves Caltrans property. Discharge points can range from ditches and pipes to connections to other drainage systems. The discharge point may consist of an outfall to another conveyance type. The discharge point always occurs at the edge of Caltrans right of way. Discharge points are the most important feature to be collected as part of the Storm Drain System Inventory (SDSI) program*.
- Outfalls: *Outfalls are locations within Caltrans property where water leaves a conveyance (pipe or ditch), and "daylights" (water leaves one conveyance to flow into another). Outfalls include asphalt or concrete overside drains*.

The Caltrans Highway Design Manual (HDM) (2001) provides design criteria and guidance for roadway drainage features, including the collection, conveyance, removal and disposal of surface water runoff from the roadway, shoulders and adjoining roadside areas. The HDM recommends that roadway drainage system design consider the drainage systems of the surrounding areas. The HDM also recommends that drainage facilities on highways and freeways with speeds in excess of 75 kilometers per hour (46.6 miles per hour) use the 25-yr rainfall event – or the rainfall event with a four percent chance of occurring in any given year – as the recommended design storm.

The HDM also provides design criteria and guidance for cross drainage features (i.e., bridges and culverts) that convey surface water through roadways or other obstructions. The conveyance of surface water may originate from an upstream location or the roadway right of way. The range of flood events to consider for cross drainage structures includes the 10-, 25-, 50-, and 100-year flood (i.e., ten-, four-, two-, and one-percent chance of occurring in any given year, respectively). Bridge structures should pass a 50-year flood with sufficient freeboard to account for bed load and debris, or in the absence of freeboard, the waterway should sufficiently pass a 100-year flood. Ultimately, the HDM recommends that the appropriate design event be selected after an assessment of the risk and economic impacts associated with flood hazards specific to the upstream and downstream areas.

The existing conditions review should document if the design criteria and / or design storm used for the existing drainage system (including roadway and cross drainage features) is consistent with the HDM, and document assumptions or deviations (if they exist) from the HDM guidelines and recommendations. The SR 92 touchdown is located between areas with potentially complex drainage considerations, including the Oliver Salt Ponds, Hayward Area Recreation and Park District Marsh (HARD Marsh), the Salt Marsh Harvest Mouse Preserve to the north, and the Eden Landing Ecological Reserve to the south, as well as the storm drain network for the adjacent industrial and residential areas east of the touchdown area within the City of Hayward (See Figure 7-1). The storm drain network consists of public roads owned by the City of Hayward, residential and industrial land owned by private parties, and flood control infrastructure managed by the Alameda County Flood Control and Water Conservation District (ACFCWCD). The surrounding watersheds of the SR 92 touchdown area cover a wide area and extend through the City of Hayward east of Mission Boulevard (See Figure 7-2). The existing conditions assessment should review the drainage connections with the adjacent areas, and document any existing drainage easements or drainage agreements that may be in place. In a large urbanized watershed, an understanding of these dynamics is necessary to conduct a meaningful assessment of the drainage system.

7.2.2 REVIEW AND DOCUMENTATION OF EXISTING MODELS

A review should be undertaken to identify and catalog existing models that can be leveraged or updated to support further assessment of the SR 92 touchdown drainage system. For example, the ACFCWCD has developed the MIKE URBAN model and other models to represent the storm drain networks within their jurisdiction. These models may include additional information on the overland flow pathways that floodwaters may take when the storm drain networks have exceeded their capacity. For example, information on the overland flow pathways over SR 92 during storm events may be available from the models. These models should be obtained (if available) and reviewed to understand the extent of the ACFCWCD system, as well as any connections between the ACFCWCD and SR 92 systems. If connections exist, the design criteria and design flows of the ACFCWCD system should be clearly documented.

This effort should also identify and catalog existing GIS layers, such as the GIS inventory Caltrans maintains for the inlets, culverts, outfalls, pump stations, etc. within a GIS environment (Caltrans 2003). A similar inventory is likely available from ACFCWCD for some of the adjacent areas, and additional information may be available from the other adjacent landowners, such as the California Department of Fish and Wildlife which owns the Eden Landing Ecological Reserve, and the City of Hayward.

The outcome of this task will be to identify a model, or suite of models, which can be used to evaluate the existing and future capacity of the SR 92 drainage system and the adjacent areas. If no suitable models exist for this assessment, then a scope of work for the modeling efforts could be developed in collaboration with Caltrans that includes developing a new model for the drainage study. The new modeling effort should place emphasis on using open source and readily available tools that can be used to support all future phases of adaptation strategy development.

7.2.3 EXISTING CAPACITY ASSESSMENT

Using the information gathered in Sections 7.2.1 and 7.2.2, the existing capacity of the current drainage system, as well as the primary drainage flow paths and connections to the adjacent areas, should be documented. This assessment should consider existing downstream Bay water levels (e.g., extreme tide events) and rainfall runoff design storms that exceed the original design criteria for the existing drainage system. This assessment will help characterize the sensitivity and limitations of the existing system. Potential recommended scenarios include:

- 25-yr storm with MHHW Bay water levels (existing design criteria)
- 25-yr storm with 5-yr, 10-yr, 25-yr, and 50-yr Bay water levels
- 10-yr storm with 5-yr, 10-yr, 25-yr, and 50-yr Bay water levels
- 50-yr storm with MHHW, 2-yr, 5-yr, 10-yr, 25-yr, and 50-yr Bay water levels
- 100-yr storm with MHHW, 2-yr, 5-yr, 10-yr, and 25-yr Bay water levels

Although the 10-year rainfall runoff event is below the typical Caltrans recommended 25-yr design storm for roadways of importance, these simulations may be helpful in understanding the performance of the system during a smaller than design storm rainfall event with higher Bay water levels, which could cause unexpected flooding. All downstream (Bay) water levels should be leveraged from the FEMA San Francisco Bay Area Coastal Study[65], or from the tidal datums study completed by the San Francisco Bay Conservation and Development Commission (BCDC) with AECOM.

The final suite of model simulations may be limited depending on the budget considerations, but the suite of model simulations should be expansive enough to understand how the existing system performs under a wider array of potential storm conditions (rainfall runoff during high[66] or extreme[67] tide events) so that the weak points or bottlenecks in the existing system (if any exist) can be identified.

7.2.4 FUTURE CAPACITY ASSESSMENT

Using the results of the existing capacity assessment as a guide, the model simulations (or a subset of them as appropriate) should be repeated with elevated Bay water levels that account for sea level rise. As shown in Figure 7-4, although the SR 92 roadway is not inundated with 24 inches of SLR, the discharge points are located within the SLR inundation zone and the capacity of the drainage system to convey rainfall-driven floodwaters from the roadway to the discharge locations may be impeded. The elevated water levels must be accounted for at each discharge location. It is recommended that this assessment consider, at a minimum, 24-, 36- and 48-inches of SLR (as shown in Figure 7-4, Figure 7-5, and Figure 7-3 respectively), coupled with rainfall runoff events from the 10-yr storm through the 50-yr storm (or until the capacity of the system is exceed, which may occur earlier than the 50-year storm event).

Potential increases in precipitation events should be considered if practical and supported by the most up to date climate science data and peer-reviewed scientific publications.

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65 www.r9coastal.org

66 High tide refers to the MHHW tidal datum; an average of the higher high tides of each day during the current National Tidal Datum Epoch (1983-2001 as defined by the National Oceanic and Atmospheric Administration (NOAA)).

67 Extreme tide refers to relatively infrequent water level events that are a result of relatively high astronomical tides coupled with a storm surge event. These levels are due to short-term meteorological processes (such as low atmospheric pressure due to storms) and large-scale oceanographic conditions (such as El Niño-Southern Oscillation). The extreme tide levels discussed in this assessment do not include any wave effects.

7.2.5 RECOMMENDATIONS

The results of the drainage study should be used to formulate recommendations that can support future drainage improvements and adaptation strategy development. The recommendations could consider the inter-connections with the adjacent landowners so that the entire system as a whole can be enhanced and / or improved to achieve greater resiliency to climate change. Examples of the types of drainage improvements that can be considered on the basis of this drainage study include consolidation of discharge points to a combined outfall location, or re-routing roadway drainage to more advantageous locations. Similarly, the types of physical adaptation strategies that could be informed by the results of this strategy include the construction of levees or seawalls.

7.3 PARTNERS

The SR 92 drainage system cannot be appropriately evaluated in isolation of the surrounding areas; therefore completion of this scope work will require active collaboration between Caltrans (which owns the drainage structures) and the adjacent stakeholders and landowners, including the City of Hayward, the Hayward Area Recreation and Park District (HARD), the Alameda County Flood Control and Water Conservation District (ACFCWCD), the California Department of Fish and Wildlife, the California Coastal Conservancy (SCC), BCDC, Hayward Area Shoreline Planning Agency, and East Bay Regional Park Department (EBRPD). Adaptation strategy design and implementation will also likely require coordination and collaboration with the adjacent stakeholders and property owners.

7.4 REGULATORY CONSIDERATIONS

The primary regulatory consideration for the SR 92 drainage study is associated with water quality. Stormwater discharges and water quality are regulated by the State Water Resources Control Board and the California Regional Water Quality Control Board (RWQCB). Caltrans maintains a Statewide Stormwater Management Plan, which was most recently updated in July 2012. As an optional task, Caltrans (in co-operation with their consultant) could consider participating in reviewing past compliance with the RWQCB permits for the SR 92 touchdown area and include recommendations for maintaining and / or improving compliance as part of the overall adaptation strategy recommendations. Any recommendations resulting from the drainage study, that consider combining or re-routing discharge locations should consider the water quality implications on the proposed receiving waters.

7.5 IMPACT ON ENVIRONMENT, EQUITY, AND MOBILITY

Given that this strategy recommends conducting a drainage study to better understand drainage networks in the Hayward Focus Area, this strategy is classified as an informational strategy. While informational strategies form the basis upon which potential physical strategies can be considered in the future, it is assumed in this analysis, that informational strategies on their own will not yield direct environmental, social, or mobility-related benefits. However, it should be noted that the results of the drainage study recommended by this strategy will directly inform potential physical strategies in the future, which will result in direct benefits, such as undisrupted regional mobility, protection of habitat, residents, and jobs.

7.6 PLANNING LEVEL COST ESTIMATION

Table 7-1 presents an approximate cost for completing the SR 92 drainage study. The cost estimate is based on similar drainage studies completed elsewhere in the San Francisco Bay. The cost estimate is presented with a range based on uncertainties related to data availability, availability of existing models, and complexity of the completed work efforts.

Table 7-1: SR 92 Drainage Study Approximate Cost Estimate

RECOMMENDED TASKS	BUDGET
Existing Conditions	$10,000 to $25,000
Existing Model Review	$15,000 to $30,000
Existing Capacity Assessment	$35,000 to $45,000
Future Capacity Assessment	$20,000 to $60,000
Recommendations	$20,000 to $25,000
Total Cost of Recommended Tasks	**$100,000 to $185,000**
Optional Tasks	**Budget**
Optional: Model Development	$25,000 to $45,000
Optional: Regulatory Considerations	$15,000 to $20,000
Total Cost of Recommended and Optional Tasks	**$140,000 to $250,000**

7.7 CONCLUSIONS

The drainage pathways and inter-relationships between the SR 92 drainage system and surrounding areas are complex and not well understood. Although several adaptation strategies are possible for the SR 92 touchdown area to provide protection from future inundation and flooding, additional information on the drainage system is needed to further inform the evaluation and development of these strategies. This section presented a scope for conducting a comprehensive drainage study for the San Mateo – Hayward Bridge (SR 92) approach in Alameda County, which includes identifying additional information on the existing drainage system, identifying important drainage connections, and conducting existing and future capacity assessments to better understand existing and future flood risks in the focus area. The results of such a study can inform future drainage improvements and adaptation strategy development.

7.8 REFERENCES

AECOM (2014) Hayward Focus Area Technical Memorandum. Prepared for the Metropolitan Transportation Commission Climate Adaptation Pilot Study.

Caltrans (2001) *Highway Design Manual, Chapter 830*, Highway Drainage.

Caltrans (2003) Discharge points, Stormwater inlet features, Stormwater outfall features for Alameda County, 2003. Compiled in ArcGIS for the MTC Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project (2011).

Caltrans (2012) *Statewide Stormwater Management Plan*.

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Adaptation Strategy: Mainstreaming Climate Change Risk into Transportation Agencies

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8. MAINSTREAMING CLIMATE CHANGE INTO TRANSPORTATION AGENCIES

8.1 MAINSTREAMING CLIMATE CHANGE ADAPTATION

California Executive Order S-13-08 (2008) paints a stark picture of the potential impacts of climate change, stating that "climate change in California during the next century is expected to shift precipitation patterns, accelerate sea level rise and increase temperatures, thereby posing a serious threat to California's economy, to the health and welfare of its population and to its natural resources." The threat applies directly to transportation infrastructure and operations, which facilitate critical access to economic, educational, cultural, and social opportunities within communities and across the State. To continue fulfilling this vital function, transportation agencies must systematically manage the risks of climate change in a cost-conscious and context sensitive way.

Transportation agencies already face a variety of challenges—from congestion to safety and state-of-good repair—and have developed robust planning and decision-making processes to address needs and prioritize actions. The premise of this strategy is that climate change risk—as one risk among many—should be managed by leveraging and occasionally adjusting existing systems and procedures, an approach referred to as *mainstreaming*. However, the challenge of climate change is potentially enormous and its full dimensions are still emerging, necessitating an integrated and coordinated approach that should involve representation across the agency. Illustrative approaches to mainstreaming, organized by the generic functional areas of Planning, Capital Development, Operations, and Administration, are offered below, along with a potential structure for agency and inter-agency coordination.

A variety of transportation agencies in California, including the California Department of Transportation (Caltrans), Bay Area Rapid Transit (BART), and the Metropolitan Transportation Commission (MTC) have taken steps to explore the issue of climate change risk as it pertains to their systems and services—although, at the time of writing, none had implemented a comprehensive mainstreaming program. A selection of key resources from California and federal partners is included below, under Resources.

8.2 ESTABLISHING A CLIMATE CHANGE POLICY

Without a mandate from top management to establish a shared trajectory toward climate adaptation, progress is likely to be incremental and piecemeal and therefore less efficient and cost-effective. A formal policy statement on climate change adaptation, preferably issued by the agency CEO/Director, board, or other governing body, lays the foundation for a comprehensive mainstreaming program, and also sends an important statement to State and federal policy makers and funders. Ideally, the policy statement will establish climate change as a critical challenge to which a coordinated, agency-wide response must be mounted, making each functional unit a full partner in the initiative. There are at least two potential paths to establishing a climate resilient policy framework: 1) the integration of climate resilience into a variety of other policies, such as risk management, asset management, or sustainability, or 2) developing a dedicated, standalone adaptation policy which will then influence all other policies. Preferably, these approaches would be pursued concurrently, as complementary strategies.

The USDOT, for example, has created an overarching climate policy (*Policy Statement on Climate Change Adaptation*, issued by then Secretary LaHood in June, 2011[68]). The Statement directed all DOT

[68] www.fhwa.dot.gov/environment/climate_change/adaptation/policy_and_guidance/usdot.cfm

administrations (e.g., FHWA, FTA, etc.) to “develop, prioritize, implement, and evaluate actions to moderate climate risks and protect critical infrastructure using the best available science and information.” It sets out eight principles to which agencies must adhere, including the adoption of integrated approaches, use of the best available science, application of risk management methods and tools, and the creation of strong partnerships. This policy is rooted in Executive Order (E.O.) 13514 – *Federal Leadership in Environmental, Energy, and Economic Performance*.

The USDOT has emphasized the need for integrated approaches and strong partnerships, in recognition that any adaptation initiative should be broad reaching and participatory—involving business units across the agency and external partners. Ideally, the policy statement will order the immediate formation of a formal adaptation coordinating committee, drawing membership from every major functional area and potentially involving external stakeholders in an observer role. The role of the committee will be to ensure a synchronized approach, leveraging the agency’s collective knowledge and resources, while also ensuring regular communication to and from individual units through a designated liaison. Although the CEO (or another member of executive management) might serve as the convener of the committee, a representative from planning, sustainability, or enterprise risk management, for instance, could play a more tactical role in scheduling meetings, developing agendas, and bringing in external resources (e.g., agency partners, academics, or consultants) to translate science and engage stakeholders and partners.

The USDOT also recognizes that an agency-wide approach to adaptation must be rooted in “the best available science” and “risk management methods and tools.” The selection of climate projections (potential future conditions), the estimation of climate impact magnitudes and likelihoods, and the valuation of risk management investments will all depend on the agency’s policies, political environment, established procedures, resources and its particular tolerance for risk over time. While science is crucial to characterizing climate change risks, the definition of risk tolerance is fundamentally a policy matter best determined by the agency or the governing bodies to which it reports. Because risk tolerance permeates every aspect of adaptation across the agency—and is particularly critical to guide investment in an environment of scarce resources and many needs—this topic should be among the first addressed by the coordinating committee.

At the state level, Caltrans is another example of an agency that has also adopted an overarching climate policy (Director's Policy on Climate Change, 2012). The Director's Policy calls for a department-wide effort to incorporate climate change mitigation and adaptation into all of Caltrans' decisions and activities[69].

8.3 INTEGRATING CLIMATE CHANGE INTO AGENCY PROGRAMS

Mainstreaming climate change adaptation into planning and decision-making processes necessitates a coordinated, agency-wide effort. However, most decision-making responsibilities are allocated to specific functional areas or divisions and follow relatively codified procedures; especially where specialized domain knowledge is required. For the purposes of this document, these core functional areas are divided into four generic groupings, as follows:

- Planning
- Capital Development
- Operations
- Administration

In practice, decision-making structures and responsibilities vary from agency to agency (as will the titles of these groups).

For each functional area, a description of potential responsibilities and duties is paired with possible mainstreaming actions. Both are intended to be illustrative, not exhaustive. Using the climate change vulnerability/strategy framework explained in section 4.2, types of strategies (*Functional, Physical, Informational, and Governance*) particularly suited to each functional area are considered. Prospective inputs to climate-resilient decision-making are also noted, as are outputs that could support decision-making elsewhere within the agency—highlighting the informational interdependencies of each functional group. Where relevant, brief case studies highlight the integration (or potential integration) of climate change risk into existing agency processes featuring examples from BART and Caltrans.

8.3.1 PLANNING

Planning units typically lead initiatives to enhance the capacity and performance of their jurisdiction's transportation systems and entities, often operating from a longer-term, strategic perspective.

Although the Planning umbrella is broad, and varies considerably by agency, the following functions are commonly carried out within the Planning functional area (or division):

- Develop and update policies/plans that establish a vision for the transportation system in the future (often 25 years out or more), including the broad outlines of projects and programs that address significant challenges (Long Range/Strategic Planning).
- Identify and prioritize projects that address critical transportation needs in preparation for project development (Capital Programming/System Expansion/System Preservation).
- Facilitate original research or research reviews in support of units across the agency, and sometimes partner agencies (Research).

[69] http://www.dot.ca.gov/hq/tpp/offices/orip/climate_change/documents/DP-30_Climate_Change.pdf

- Enhance coordination with modal operating agencies, such as rail carriers, airport authorities, or transit agencies (Multimodal Planning/Systems).
- Support local agencies to improve the performance of their transportation systems in conformance with federal guidelines (Local Aid/Assistance).

Potential Role of Planning in Climate Change Adaptation Activities

Planning units are well suited to addressing Informational vulnerabilities directly, as the manager of an agency's long-term priorities and a key provider of research (and potentially data). In their coordinating or convening capacities (with other modes and agencies), Planning units may also contribute to resolving Governance vulnerabilities. Specific potential contributions to enhancing resilience and climate change adaptation include:

- **Convening.** Although a comprehensive, agency-wide approach to mainstreaming climate change adaptation ideally starts as a strategic priority at the Executive level, the Planning functional area is well suited to provide direct support and/or technical advice to an agency-wide (or inter-agency) coordinating body.
- **Coordinating.** Planning units, through activities such as local assistance and modal planning already coordinate with external partners to address a variety of challenges and provide guidance on process and compliance issues. This role could be expanded to encompass matters of climate adaptation by forging new connections to knowledge partners (e.g., research institutions and peer agencies already addressing climate change[70]) and then serving as a conduit between them and local/modal partners, as well as internal business units.
- **Knowledge Generation/Data Provision.** Research units (a fixture of state DOTs, primarily) fulfill the role of developing new knowledge or consolidating existing knowledge to address research needs statements submitted by internal functional units (sometimes extending to agency partners). Units generally leverage partners from the academic community or consultants to carry out the research program, and submit the resulting documentation to the public Transport Research International Documentation (TRID) database. The Research unit provides an opportunity to generate tailored knowledge on climate projections, potential impacts to transportation infrastructure and operations, support development of specific climate risk ratings oriented to the specific decision-making processes of internal business units, and translate science and other technical information for colleagues, stakeholders, and decision-makers.
- **Strategic Visioning.** Planning oversees the establishment of the agency's long-term vision and strategic direction and objectives—including the identification of anticipated challenges and broad programs to address them. The expected impacts of climate change could be integrated into this process—which may include statements on the agency's vision, values, mission, goals, performance indicators, and programs for implementation, for example--alongside of more traditional transportation challenges generally affecting the agency's systems, operations, and activities (e.g., congestion, accessibility, safety). Climate impacts could also feature in planning scenario analyses to better ensure the resilience of major investment programs (such as system expansions or enhancements, for example).
- **Needs Identification/Prioritization.** Depending on the agency, the transition from plan to project (and from Planning to Capital Development or Project Development units) might occur as a screening step, wherein specific problems are framed (needs identification) and prioritized, and for which project concepts are developed and analyzed. Climate risk could be integrated into this process as a filter or screen; a "need," for example, could be mitigation of chronic, disruptive

[70] For example, an agency such as the Alameda Flood Control District might work with a transit agency, like BART, to develop a comprehensive strategy for flood mitigation around critical BART assets, such as the Coliseum station.

flooding of a specific facility that is expected to grow more frequent and severe in the future. Similarly, climate risk could feature as a factor in alternatives analysis, particularly as it potentially affects the ability of a project or program to achieve its underlying objective (e.g., if an enhancement to mitigate a critical bottleneck is expected to be frequently affected by future high tides, lowering its efficacy, the project concept may require revisiting prior to project development).

Informational Interdependencies

- **Inputs:** Ideally Planning units require at least four types of inputs in order to effectively mainstream climate change into their processes: 1) a policy mandate and goals framework, from Executive management; 2) information on climate projections from research entities or other agencies, and 3) an articulation of climate risk-related project needs and data gaps from other business units (through research statements or facilitated dialogue); and 4) information on current extreme weather vulnerabilities and/or risk management responses to those vulnerabilities. Example 1 provides information on an existing policy at BART, in which climate change considerations can be incorporated. Example 2 shows an existing Caltrans resource which contains information on whether and how climate change risk should be incorporated into projection initiation processes.

> **Example 1: Sustainability Policy (BART)**
>
> *BART's Sustainability Policy establishes the agency's sustainability goals and vision which includes BART's "role in regional sustainability", "social and environmental quality of life", and "long-term economic prosperity and entrepreneurial spirit".*
>
> *The current policy does not explicitly incorporate climate change adaptation, which was generally only an emerging concern for transportation agencies in 2008 (the year the USDOT Gulf Coast Phase 1 Study was issued). However, the policy could be readily adapted in the next update.*
>
> *More information on the Sustainability Policy is available at http://www.bart.gov/about/planning/strategic.*

- **Outputs:** Planning units are positioned to facilitate the development or intake (from other entities) of information and data on climate projections and priorities, and to disseminate that information to a variety of business units as inputs or guidelines for decision-making, as well as to executive management to inform policy-making and agency wide coordination.

8.3.2 CAPITAL DEVELOPMENT

Capital Development units are typically responsible for facilitating the development and implementation of projects. Depending on the agency, the function of capital development may be carried out by a single unit or spread among multiple units. The following functions are commonly carried out within a Capital Development functional area:

- Prioritize and scope projects for design development (Capital Programming).
- Ensure environmental compliance of projects and/or steer projects through environmental permitting processes (Permitting/Environmental Analysis).
- Acquire right of way, perform land surveys, and manage access (Right of Way).
- Manage project concept design and development, engineering processes, and construction (Project Management/Design/Engineering/Construction Services).
- Develop, publish, and maintain design guidelines, standards, and specifications (Capital Program Support/Materials).
- Manage infrastructure renewal investments (Asset Management).

Example 2: Guidance on incorporating SLR in Project Initiation Documents (Caltrans)

In 2011, Caltrans issued its Guidance on Incorporating Sea Level Rise: For use in the planning and development of Project Initiation Documents, which traces its lineage to Executive Order S-13-08 (2008). The Guidance emphasizes the incorporation of sea level rise (SLR) into Project Initiation Documents (PID), which record decisions on scope, cost, and schedule for major projects on the State Highway System (SHS). The Guidance commences with an explanation of the rationale and purpose for addressing SLR—"To reduce the impact [of SLR] on project delivery in the future"—and explains the approach to estimating SLR adopted by the California Climate Action Team (CCAT).

The majority of the Guidance is dedicated to explaining the process for "Determining and Documenting Whether to Incorporate Sea Level Rise in Project Programming and Design." The process begins with a screening step, wherein the potential impact of SLR on a given project is determined and documented (similar in concept to an Environmental Assessment, for which a Finding of No Significant Impact allays the need for further analysis). If further analysis is required, the Project Development Team (PDT) is asked to "balance" the factors of timeframe (project lifespan), consequences (the impacts of SLR, as mitigated or exacerbated by adaptive capacity or the lack thereof), and risk tolerance (based on the consequences and costs of over- or under-estimating SLR, particularly as the century progresses). A series of sample screening criteria are included to facilitate the determination of whether, ultimately, SLR is incorporated into the project (see Guidance Table 1).

If the PDT determines that SLR is to be incorporated into the project, the Guidance provides a grid of global SLR scenarios standard for the State (providing consistency across agencies and geographies), which are to be adjusted for local project conditions (such as subsidence or uplift). Projections for 2070 or beyond are expressed as ranges, with the specific value to be selected by the PDT ("there is no specific 'right' or 'wrong' value"). When, based on a screening analysis, the impacts of SLR are expected to be significant, the PDT is requested to develop adaptive measures, the costs of which are included in the project estimate as a separate line item. Because the understanding of SLR and its potential impacts on transportation infrastructure are evolving, the Guidance is "subject to revision as additional information becomes available."

More information on the Guidance is available at:
http://www.dot.ca.gov/ser/downloads/sealevel/guide_incorp_slr.pdf

Potential Role of Capital Development in Climate Change Adaptation Activities

Capital Development units are well suited to addressing *Physical* vulnerabilities, as the traditional leader of design, engineering, and construction activities. Given their close coordination with environmental agencies, units responsible for permitting/ environmental analysis could play a role in addressing *Governance* vulnerabilities. Specific potential contributions to enhancing resilience and climate risk preparedness include:

- **Project Prioritization.** Depending on the agency, a project concept may be selected for development by Planning or Capital Development units—or in a coordinated or iterative effort between the two functional areas. As described under "Planning," climate risk could be integrated as a project selection filter and/or could be considered as a dimension of other screening criteria.
- **Project Development/Scoping/Preliminary Engineering.** As a project takes shape, the consideration of climate change risk could flag fundamental design challenges prior to project engineering and spur consideration of adaptation features. For example, rehabilitation of a substation in a flood-prone area could trigger design considerations for raising the elevation of the asset above the flood stage.
- **Design Guidelines, Standards, and Specifications.** Prevailing design guidelines, standards, and specifications can be updated to reflect the agency's risk tolerance and guide the project's design. Particularly for long-lived or very vulnerable asset types (e.g., bridges and culverts), these documents could be updated based on projected future risk factors and/or failure trends. Examples 4 and 5 show an existing Caltrans and BART resources on highway and facilities design respectively, in which climate change risk can be incorporated.
- **Project Engineering.** Project engineering units apply the agency's design guidelines and specifications in advancing a project from concept to detailed (constructible) design (often, actual design is carried out by contractors under agency supervision). Nonetheless, a typical design and engineering process provides several opportunities for discretionary decision-making, oftentimes related to the selection of the appropriate standard or guideline in a given case. These opportunities are potential occasions for climate smart decision-making, but engineers (whether agency or contractor) require explicit guidance, training, and authorization in order to take advantage of them. Engineering activities may also take place in the Operations & Maintenance functional area (see below).
- **Permitting.** Permitting can be critical to enabling proactive adaptation and managing the post-disaster response. Permitting is often supported by a specialized unit, particularly at state DOTs, but diverse business units across the agency engage with multiple permitting processes, including CEQA/NEPA or debris removal and oversize/overweight permits (in the wake of a disaster), for example. Although a robust permitting framework is important, it may be that infrastructure slated for replacement or reconstruction (whether as part of the asset renewal cycle or post-disaster, due to damage) is rebuilt to the same (vulnerable) standard because of permitting constraints that make the consideration of betterments so challenging or time consuming as to be infeasible. A proactive dialogue with partner environmental agencies could support the identification of solutions that protect the environment (and adjacent landowners) while turning asset renewal activities, and even disasters, into opportunities to enhance the resilience of otherwise vulnerable facilities.
- **Asset Management.** Among the core principles of asset management is intelligent investment—ensuring that the agency's scarce resources are deployed in such a way that enhances system performance (or minimizes performance losses). Climate risk affects system performance today—from minor operational disruptions to premature deterioration and significant damage or destruction—and many of those risks are expected to increase in frequency and/or severity in the future. By incorporating projected future risks into asset management regimes today, the asset renewal cycle (including capital investments as well as operations and maintenance) and specific treatments can be adjusted to maximize the agency's investment dollars. Example 3 provides information on an existing asset management program at BART, in which climate change risk can be incorporated.

Example 3: Asset Management Program (BART)

BART has developed an asset management strategy in accordance with the Moving Ahead for Progress in the 21st Century Act (MAP-21), which requires transit agencies to develop risk-based asset management plans. This strategy "integrates [the] extent of investment needed to meet desired service levels while managing the risk to reliable service" (Ruffa, TRB 2014)1. It includes six different asset classes, including Guideways, Revenue Vehicles, Non-Revenue Vehicles, Facilities, Systems, and Support Services. The system is set up to test a series of "Risk Response Options" over a 10-year period, which helps characterize and communicate 1) the level of investment required to meet system condition goals and 2) the compromises to service required if adequate funding is not identified.

Although characterized as a "work in progress," the agency's risk management focus indicates that the system could evolve to include "climate risk management"—alongside or as a dimension of more traditional "key strategic risks" like "age and condition of infrastructure," "loss of skilled people," and "increased customer ridership" (straining system capacity).

The Bay Area Rapid Transit Climate Change Adaptation Assessment Pilot (Draft 2013) considers the integration of climate change risk into the agency's nascent asset management system, and discusses specific opportunities at the enterprise and asset level where BART can integrate climate change adaptation. BART concludes that the next step is a system-wide vulnerability assessment which could inform its Asset Management group's risk profiles. This step could be integrated into the ongoing effort to improve the data management, risk quantification, and options evaluation capabilities of the system.

Informational Interdependencies

- **Inputs.** The statement of project need may originate in Planning (and is typically tied to a broader strategic purpose) or Operations (based on existing conditions). Ideally information on potential climate risks would also come from Planning—although these inputs may be further refined within Capital Development. An "official" profile of future risks, perhaps developed by Planning but authorized at the Executive level, is a critical input into revised design guidelines and specifications, asset management programs, and permitting dialogues. Empirical information on current and chronic vulnerabilities or premature failures—providing valuable insight into potential future challenges—can be collected from Operations units.
- **Outputs.** The most visible outputs of Capital Development are projects, including rehabilitations, reconstructions, replacements, or, more rarely, new assets. These assets are then inherited by Operations for routine, preventative, or reactive maintenance. Assets that successfully manage climate risks, among other priorities, will on balance tax fewer operational resources.

Operations & Maintenance

Operations & Maintenance units are typically responsible for day-t o-day system management. Operations & Maintenance functions might be grouped together as a single functional area, or split into two (or more) functional areas, most often along the lines of physical maintenance, traffic operations, and/or police (for transit agencies). The following functions may be carried out within an Operations & Maintenance functional area:

- Perform preventative and reactive maintenance of transportation infrastructure and/or rolling stock (Maintenance)[71]. This function often includes tactical, small-scale engineering.
- Traffic operations and/or system service (Traffic Operations/Operation Control Center).

[71] Although many asset management activities are carried out by Maintenance personnel, because asset management is an investment decision-making activity it is included under Capital Development.

- Emergency management planning, response, and coordination (Emergency Management/System Safety).
- Transit public safety (Transit Police).

Example 4: Highway Design Manual (Caltrans)

Like all state Departments of Transportation (and a variety of other transportation agencies), the California Department of Transportation (Caltrans) publishes a Highway Design Manual (alongside of other design resources, such as the Bridge Design Specifications). The Manual, or HDM, is an expansive guide to Caltrans' highway design policies and procedures, covering several hundred pages (and therefore the examples offered below should be considered as illustrative).

Caltrans specifies that "many of the instructions given herein are subject to amendment as conditions and experience warrant"—which, in theory, creates an opening for the integration of climate risk, either as a Special Consideration or more comprehensively. A potential model for the former approach is Earthquake Considerations (Section 110.6), which states that "every attempt should be made to limit potential damage" from a seismic event. Designers are instructed to, for example, map active and inactive faults, with the assistance of the Office of Structural Foundations. Based on the fault mapping exercise, major interchanges "must be sited outside of heavily faulted areas unless there are exceptional circumstances…." Further, designers are instructed to balance additional expenditures for the purpose of making roadways "more earthquake resistant" with the likely impact of such an event on the traveling public (major interchanges are expected to have "a tremendous influence on traffic flow"). A similar Special Consideration also could be instituted for Sea Level Rise, or other climate-related phenomenon.

Another, potentially complementary approach, would be to consider ranges of potential future change where weather-related design factors are addressed currently—commensurate with the functional classification and expected lifespan of the asset under design. For example, the "design storm" is a critical element for drainage design (Sections 800-890), providing a probabilistic exceedance factor based on the Department's risk tolerance for several different facility classifications (e.g., Freeways and Conventional Highways). The design storm is expressed as an annual exceedance probability (e.g., 2%, 4% or 10%), and depending on the method used to estimate discharge, the distribution of rainfall over time may also be required (e.g., a depth-duration-frequency, or DDF, curve). For discharge estimation methods that use empirically or statistically derived design storm values (such as Rational or TR55), the designer might also be asked to consider one or more potential future design storms, in addition to values from NOAA's Atlas 14 or other standard sources. Other methods, such as the USGS Regional Regression Equations, which use mean annual precipitation, might need to be reevaluated and/or adjusted (see HDM Table 819.5A for a summary on design discharge estimation methods).

More information on Caltrans' design manuals and related guidance documents is available at http://www.dot.ca.gov/manuals.htm.

Example 5: BART Facilities Standards (BFS) (BART)

The BFS is a set of standards that regulate the design of the BART facilities and infrastructure. This document is maintained and updated by the Maintenance Engineering & Planning and Development Departments.

The BFS specifies the 100-year storm event as the design storm for assets such as the track-way. The BFS also requires designing to the 500-year flood stage for critical assets. Critical assets include vents, traction power, train control, and communication buildings.

The BFS version 3.0.1 includes physical adaptation strategies for designers to consider for protection against downpours, sea level rise, and riverine flooding.

Potential Role of Operations & Maintenance in Climate Change Adaptation Activities

Operations & Maintenance units often directly address Functional vulnerabilities, many of which are caused or triggered by a Physical vulnerability. Also, Operations & Maintenance personnel are typically the first responders when Physical failures occur, whether to monitor the condition and safety of assets (e.g., scour critical bridges), perform reactive maintenance to restore operations, or—in extreme cases—to close and stabilize a facility that has failed and will require major reconstruction. Maintenance personnel witness (and work to correct) asset deterioration and failures first hand, and therefore their input to design engineers can help bridge Informational gaps pertaining to design performance. Emergency Management units coordinate broadly with a host of local, regional, state, and national entities, and as a result are equipped to help manage Governance vulnerabilities.

Because of the (generally) shorter-term focus of Operations & Maintenance units, there may be fewer direct opportunities to mainstream climate change for this functional area. Nonetheless, Operations & Maintenance is an important collaborator with internal units and external partners as they prepare for climate change, particularly in terms of providing valuable information about existing vulnerabilities and repair costs. Specific potential contributions to enhancing resilience and climate risk preparedness may include:

- **Emergency Operations/Evacuation.** The next iteration of the Bay Area *Regional Transportation Emergency Management Plan* (RTEMP) is anticipated to include climate change considerations. The RTEMP and other emergency response preparedness plans could benefit from the most current projections for future extreme weather and climate conditions (like SLR), which could be used to frame the potential change in the frequency, magnitude and required resources of future emergencies. . Example 6 provides information on an existing Emergency Plan at BART, in which climate change risk can be incorporated.
- **Coordination.** Particularly in its emergency response function, of which traffic operations is a critical component, Operations & Maintenance units forge relationships with a variety of entities at multiple levels of government, from local governments to federal agencies. Many of these relationships could be leveraged to help the agency as a whole develop more robust responses to climate change that extend beyond the traditional right-of-way.
- **Maintenance Feedback.** Maintenance personnel are first-hand witnesses to the success or failure of design and engineering strategies (including materials selection), whether during extreme weather events or in the course of day-to-day maintenance (as documented in maintenance management systems), and therefore can often provide valuable feedback, including repair costs, to Capital Development units. However, there rarely exists an explicit feedback loop between these groups.
- **Purchasing and Funding.** Better documentation of extreme weather frequencies and trends may support enhanced preparedness by helping to inform longer term purchases of materials (e.g., road salt or drought-resistant roadside vegetation) or equipment (e.g., emergency-response

trucks or specialized tools). Documentation of a consistent shortfall in availability of key materials or equipment may support the case for increased funding.

Informational Interdependencies

- **Inputs.** The climate projections and scenarios adopted by the agency will provide useful perspective to Operations units, particularly in the preparation of emergency preparedness plans—although there may be little need to incorporate long-term projections directly.
- **Outputs.** Information on existing vulnerabilities or premature failures could be provided to Capital Development units to enhance future engineering practice. Emergency Management units could also serve as an information conduit, helping to connect the climate change activities and initiatives of coordinating entities with those of the transportation agency.

Example 6: BART Emergency Plan

The BART emergency plan is divided into two types of emergencies: 1) those that require significant outside resources (through City, County, State, and Federal agencies) that warrant the activation of an Emergency Operations Center (EOC), and 2) those that do not require resources beyond those available within BART except the fire department, emergency medical services, and coroner support. These types of emergencies are largely managed internally through the Operations Control Center (OCC). Both types of emergencies may be expected by climate change.

The Plan includes protocols and systems for various incidents including those for extreme weather events. The flooding and high wind velocity sections of the Plan include protocols for addressing these incidents. Protocols in both these sections include contacting the National Weather Service Office for updated reports on weather conditions. In responding to earthquakes, BART maintains an automated system that receives seismic data from the California Integrated Seismic Network through UC Berkeley. The system evaluates the seismic data and automates an appropriate response to train operation personnel. Innovative solutions like these can serve as a model for improving the response timeline to extreme weather events.

BART's Emergency Plan presents a prime opportunity for the agency to further integrate climate change considerations into its operations. Specific opportunities for integrating climate change may include 1) emergency planning considerations such as preparedness with sand bags, boarding material, pumps. 2) close review of the adequacy of existing procedures for extreme weather events to account for climate change, 3) testing of the Plan using extreme weather event scenarios.

8.3.3 ADMINISTRATION

Administrative units are important partners in mainstreaming adaptation, ideally facilitating the progress of Planning, Capital Development, and Operations & Maintenance units.

The following functions may be carried out by Administrative units:

- Overall agency leadership, strategic policy-making (Executive Management);
- Managing relationships with the public, media, and elected officials (Public Relations/Media Relations/Government Relations);
- Working with technical units to develop and manage budgets and establish funding streams (Finance/Budgets);
- Managing cross cutting agency initiatives, like risk management or sustainability (Enterprise Risk Management/Sustainability);
- Managing the agency's non-transportation resources (Physical Plant/Support Services /Information Technology);

- Supporting the activities of the agency by enabling procurement and contracting, providing legal advice and services, performing accounting and payroll functions, and human resources, for example.

Potential Role of Administration in Climate Change Adaptation Activities

With a very broad range of potential duties falling under the mantle of Administration, units within this functional area may address at least the following vulnerabilities: Governance (e.g., Executive Management), Informational (e.g., Enterprise Risk Management), and Physical (e.g., Physical Plant for non-transportation assets). Specific potential contributions to enhancing resilience and climate risk preparedness may include:

- **Executive Management.** The active backing of executive management is of crucial importance. Agency leadership develops policy, sets priorities, serves as a liaison to other governmental entities, and has cross-departmental authority and responsibility. Executive management is the ideal convener of an inter-departmental climate change coordinating committee (although its day-to-day operation may be managed by another unit, such as Planning or Sustainability, for example), and can also help elevate issues, such as permitting requirements, that must be addressed with external partners.
- **Government Relations.** Administration is a critical partner in supporting adaptation dialogue with partner agencies and legislative bodies. For example, administration divisions can serve as active participants in AB32 rule-making.
- **Public/Media Relations.** This unit can support the articulation to stakeholders (including the traveling public and businesses) of the need to address climate change in agency activities.
- **Finance/Budgets.** Most impacts of climate change and extreme weather manifest financially, in the form of emergency repair budgets and additional labor and equipment costs during and in the aftermath of disasters, for example. Adaptation actions also might entail additional expense (e.g., the marginal cost to build a more resilient facility), which must be balanced with estimated risks. Finance and budget units can support the development of standardized approaches to valuing adaptation actions and making appropriate trade-offs, and can also help project future budget needs agency wide given anticipated changes in climate.
- **Facilities/Physical Plant.** In addition to transportation assets that serve businesses and the traveling public, agencies rely on other types of physical facilities that support the operations, including office space, maintenance yards and shops, traffic control centers, traction power stations, and even commercial real estate. Managers of these facilities should be engaged on climate change impact issues, although each facility may have differing sensitivities to climate change.
- **Sustainability.** Many agencies have a dedicated sustainability unit, which works across departments to support more environmentally-friendly practices. The Sustainability unit may have specialized domain knowledge to contribute, and can also be seen as a neutral coordinator of cross-departmental activities. Because sustainability is a multi-faceted concept, this unit may be well suited to identifying key co-benefits of adaptation actions
- **Enterprise Risk Management (ERM).** Some agencies, including Caltrans, have a dedicated ERM office responsible for managing inherent uncertainties across the agency. ERM activities commonly address threats to the ability of the agency to fulfill its mission and objectives, and may extend to programmatic and even project-level risks. Climate change risk can be integrated into most ERM frameworks and initiatives.
- **District Offices.** Departments of Transportation of larger states, in particular, often maintain several district offices. District personnel often possess an unparalleled knowledge of regional or

local priorities, risks, and effective risk management strategies, and are therefore crucial partners in addressing climate change.

Informational Interdependencies

- **Inputs.** Direct knowledge of the extreme weather and climate change challenges faced by technical units will help Administration set strategic priorities, communicate with the public/media and elected officials, and integrate climate as an element of existing risk management initiatives, for example.
- **Outputs.** Administrative units may be well equipped to represent the challenges faced by the agency to a broader, often non-transportation audience, and to solicit guidance and resources from other agencies and legislative bodies. Administration is also a key conduit of broader, contextual information from external sources to the agency's technical units.

8.4 FUNDING

Mainstreaming implies that climate change risk is treated as a fundamental condition of programs or projects—such as seismic risk or unstable soils—and is therefore addressed through standard budgeting and funding mechanisms. However, several potential options exist, or are emerging, that may be leveraged to provide dedicated supplementary funding, including:

- **Grants.** Grant programs, such as the recent pilots administered by Federal Highway Administration and Federal Transit Administration, provide a dedicated funding source oriented toward planning level climate change risk and adaptation assessments (and, more recently, concept-level engineering-based assessments of specific assets). These grants typically require an agency match. Agencies that have demonstrated a broader commitment to climate change adaptation may be better positioned for future funding opportunities.
- **Bond Issues.** Major, system wide risks (such as SLR) may require large infusions of funds over relatively short periods of time, far exceeding revenues from traditional sources. In this case, the agency may seek to issue General Obligation (GO) bonds, with revenues dedicated to addressing a specific set of risks. For example, BART's GO bond issue, presented to voters as Regional Measure AA, provided $980 million to make earthquake safety improvements to BART facilities in three counties. BART anticipates that the retrofits and projects funded by this bond issue will be completed by 2018. General Obligation bond issues typically require voter approval.
- **Insurance.** Insurance payouts are an important source of post-disaster recovery funds. Certain insurance products (called parametric policies) offer settlements based on the occurrence of a triggering event (the exceedance of a specific threshold). In instances where payouts exceed actual losses, surplus funds could be applied to increasing system wide resilience, reducing the agency's risk and thereby, potentially, its insurance premiums.
- **Disaster Aid.** In 2012, FHWA issued a clarifying memorandum addressing the eligibility of "activities to adapt to climate change and extreme weather events" under the federal-aid program.[72] Although the memorandum specifies that no additional funding is available for adaptation activities, federal-aid funding may be applied to risk assessment efforts, lifecycle costing, and project expenses. Significantly, cost-effective "betterments" (improvements) to increase the future resilience of facilities damaged in a disaster are deemed eligible for federal Emergency Relief (ER) funds.
- **Fees/Taxes.** Although the creation of fees and taxes is often a politically fraught topic, in theory both mechanisms could be used to raise revenues for adaptation. Fees, which would be assessed only for users of specific services or facilities, could be applied in the form of tolls or fares. Revenues from these sources could potentially support the issue of Revenue bonds, which would provide a greater amount of up-front funding. Tax-related sources could include a special assessment (a penny sales tax, for example), a transportation specific tax (such as a fuels tax),

72 http://www.fhwa.dot.gov/federalaid/120924.cfm

or a general tax (although competition for new revenue across the board may create challenges for transportation agencies).

- **Cap and Trade (AB32).** California's greenhouse gas (GHG) cap and trade program generates revenue by auctioning emission permits within capped sectors. The revenues from AB32 have not, to date, been available for transportation adaptation (the largest 2014-2015 appropriations were to High Speed Rail and the Clean Vehicle Program). Hypothetically, however, a portion of this revenue stream—estimated over time to generate $2-5 billion annually—could be appropriated to climate risk adaptation. This would likely require substantial agency engagement with elected officials.

The relevance of these funding sources to adaptation mainstreaming depends greatly on the specifics of each mechanism. The use of marginal costs (costs related to adaptation above and beyond baseline investment costs) is suggested whenever possible in order to determine the most appropriate funding source for mainstreaming.

8.5 IMPLEMENTATION PROCESS

The comprehensive mainstreaming of climate change into agency processes is a significant, potentially daunting undertaking—but also one of critical importance. Establishing a pathway for implementation is an essential part of this process. Ideally, the pathway will outline a series of logical steps—short-, medium-, and long-term—that incrementally build toward full integration over time. The actual timeframe, and indeed the steps themselves will depend greatly on the agency's starting point, the level of broader political and institutional support (and shared knowledge), and the commitment and continuity of agency leadership. Generally, the following five steps could be used to describe the progression of an agency toward full mainstreaming:

1. **Review Current Practice**. The agency convenes a working group and commences an outreach/interview program to develop a thorough understanding of existing decision-making processes—as well as climate-related challenges and concerns—among relevant units and agency wide. This effort helps establish key needs and opportunities, as well as exemplary practices that may be more broadly applied. At this stage, the agency should begin formulating a broad policy statement on climate change, which can be fleshed out and refined subsequently.
2. **Establish Programs.** The review of current practices establishes where an agency is starting from. The next step is plotting a realistic, appropriately sequenced trajectory from current practice to full mainstreaming, supported by a strong policy framework. An agency might select objectives and success indicators (by unit and agency-wide), and then work with business units to chart the course—recognizing dependencies internal and external to the agency. The result will be a series of programs (e.g., "update Specifications and Design Standards"), each charged to a staff member (within the relevant business unit) who bears responsibility for progress, but is also sufficiently empowered to ensure implementation. This is also the stage at which climate projections are produced to support program implementation, as needed. The agency coordinating committee should continue to meet throughout the implementation process and periodically thereafter to monitor progress.
3. **Build toward Implementation.** This step includes the launch of the first wave of programs, sequenced in relation to key informational dependencies. This might mean factoring climate change into early stages of the project pipeline, particularly long-range plans, or developing information to support the revision of a process (such as setting up the maintenance management system to provide more robust data on extreme weather related failures in preparation for a mainstreamed approach to asset management).
4. **Implement Decision Support Systems/ Processes**. This step, really a continuum from Step 3 and on to Step 5, includes the development of intermediate products essential to full implementation and/or piloting of newly revised processes (for example, the full integration of

climate risk into the design and engineering process and post-design assessment of changes in risk and cost). Activities in this step could require multiple iterations or refinements prior to successful integration.

5. **Achieve Full Integration of Climate Risk**. At this stage, a given unit—and eventually the entire agency—has effectively integrated climate change considerations into all relevant decision-making processes. As with any process, particularly in a field where scientific knowledge and policy approaches are rapidly evolving, it will be necessary to monitor outcomes and reevaluate these approaches (and supporting policies) periodically.

8.6 RESOURCES

The following published or online resources may be instructive to transportation agencies, in California and elsewhere, seeking further information on climate change adaptation in the transportation sector. These examples represent a small selection of available resources.

Research on The Potential Risks Of Climate Change To Transportation Agencies

- U.S. DOT. *Gulf Coast Study: Impacts of Climate Variability and Change on Transportation Systems and Infrastructure, Phase 2* (2014).[73]
- Bay Area Rapid Transit. *Climate Change Adaptation-Assessment Pilot* (2013).[74]
- MTC. *Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project* (2011).[75] Phase 1.

Guidance for Transportation Agencies Seeking To Identify Climate Change Risks And Develop Adaptation Strategies

- NCHRP Report 750: *Climate Change, Extreme Weather Events, and the Highway System* (2014).[76]
- Caltrans. *Addressing Climate Change Adaptation in Regional Transportation Plans: A Guide for California MPOs and RTPAs* (2012).[77]
- FHWA. *Climate Change & Extreme Weather Vulnerability Assessment Framework* (2012).[78]
- FTA. *Flooded Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation (*2011).[79]

Sources of Climate Change Data/Projections

- California Energy Commission. Cal-Adapt (website).[80]
- NOAA. Climate.gov (website).[81]
- NOAA Office of Global Programs. California-Nevada Climate Applications Program.[82]
- Our Coast Our Future (OCOF) (website).[83]

[73] www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/gulf_coast_study/
[74] bids.mtc.ca.gov/download/519
[75] http://www.mtc.ca.gov/planning/climate/RisingTides-TechnicalReport.pdf
[76] http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_750v2.pdf
[77] www.dot.ca.gov/hq/tpp/offices/orip/climatechange/documents/ FR3_CA_Climate_Change_Adaptation_Guide_2013-02-26_.pdf#zoom=65
[78] www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and _tools/vulnerability_assessment_framework/
[79] http://www.fta.dot.gov/documents/FTA_0001_-_Flooded_Bus_Barns_and_Buckled_Rails.pdf
[80] http://cal-adapt.org/
[81] http://www.climate.gov/maps-data
[82] http://cnap.ucsd.edu/
[83] http://data.prbo.org/apps/ocof/

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9.0 Lessons Learned

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9. LESSONS LEARNED

9.1 INTRODUCTION

This section outlines the lessons learned from the project, particularly challenges to obtaining and applying data, and assessing and selecting adaptation strategies. Where appropriate, solutions to overcome these challenges are included.

9.2 LESSONS LEARNED

9.2.1 DATA COLLECTION

The data collection exercise benefited from the first round MTC pilot for which a limited amount of information was collected on all the key assets under consideration. In addition, BCDC's ART project had initiated data collection efforts for each of the project's focus areas. However, despite this, the Technical Team spent considerable effort gathering more data through a survey monkey questionnaire which had 150 questions per asset and a further 50 questions per identified component of the asset. The questions were organized by governance-related challenges; informational challenges; physical characteristics; functional characteristics, and consequences of climate change. Specific component questions were required due to the answers potentially being very different depending on the different components. For example, the physical characteristics of the Toll Plaza are very different to the Temescal Creek Bridge, yet both are important components of the I-80/I-580 segment between Powell Street to the Toll Plaza.

There were 20 core and adjacent assets requiring a total of 3,000 potential questions to be answered and 21 key asset components requiring a total of a further 1,050 potential questions to be answered. The information was particularly hard to find for many of the adjacent assets since they are not owned or operated by the project partners; however, the information was often not available for the asset components even if owned or operated by the project partners. For this reason, many questions were left unanswered. Despite, or because of this, lots of time was spent attempting to answer the questions. However, given that ultimately adaptation strategies were only developed for 5 of the assets or asset components, much of the data was not used in detail for the project. Some of the data collected was used to inform the vulnerability assessment of each of the assets and their components (particularly the physical information) and some of it was used to inform the economic and mobility impacts of the 5 adaptation strategies. There needs to be a balance between collecting data at an early stage in the project to help decide which assets are most vulnerable and at risk and therefore need prioritization for adaptation, and then once those assets are identified, collecting further data to help develop appropriate adaptation strategies. Questions that were consistently unanswered could be removed from future studies until such time as data collection is known to be more robust; however, before removing questions from such an analysis, thought should be given to whether the information might useful in the future.

It is noted however, that all the information that was collected was geo-coded, whether qualitative or quantitative. It is expected that having the data recorded as a GIS attribute will be very useful for the agencies in future when the vulnerabilities of different assets are re-examined and further adaptation strategies developed.

Survey respondents included all members of the project Technical Team. The Technical Team members also delegated the data collection task to colleagues within their organizations as needed. It was critical to identify an appropriate person within an organization to answer the question adequately. Information was sourced from a variety of people and departments across the different agencies.

9.2.2 VULNERABILITY REFINEMENT

A clear lesson learned from the first MTC pilot study was the limitation in producing maps containing a large difference in the inundations from two SLR scenarios (16-inch and 55-inch) and SLR + 100 year storm surge scenarios. This project therefore undertook a more refined analysis of potential exposure to future sea level rise. The full methodology for this new analysis is described in Chapter 3 and was a very useful tool for the project team, both in understanding timing and onset of sea level rise and how it relates to flooding from existing storm events as well as in communicating the vulnerability to stakeholders. It is highly recommended that this type of analysis be carried out in similar projects, contingent upon the availability of technical resources such as models and data.

For example, understanding that a MHHW + 24-inch SLR inundation scenario is equivalent to flooding from 5 year storm event under existing conditions is a very powerful and understandable message (see Table 9-1 and cells highlighted in orange).

If the sea level rise or storm surge mapping doesn't align with local knowledge of existing flooding, a thorough field visit should be carried out to verify the vulnerabilities. The shoreline overtopping assessment was very helpful at highlighting which vulnerable locations needed to be verified in the field. In particular, the Technical Team-visit to the Hayward Waste Water Treatment Plant and the Radio Beach area north of the Bay Bridge Toll Plaza were extremely helpful. Where possible, maintenance field staff should participate in field assessments as there may be opportunities for significant sharing of knowledge.

Table 9-1: Matrix of Water Levels Associated with Sea Level Rise and Extreme Tide Scenarios for the Hayward Focus Area (also Table 3.2)

	Daily Tide	Extreme Tide (Storm Surge)						
Sea Level Rise Scenario	Water Level above MHHW	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Existing Conditions	0	15	20	24	27	32	36	41
MHHW + 6-inch	6	21	26	30	33	38	42	47
MHHW + 12-inch	12	27	32	36	39	44	48	53
MHHW + 18-inch	18	33	38	42	45	50	54	59
MHHW + 24-inch	24	39	44	48	51	56	60	65
MHHW + 30-inch	30	45	50	54	57	62	66	71
MHHW + 36-inch	36	51	56	60	63	68	72	77
MHHW + 42-inch	42	57	62	66	69	74	78	83
MHHW + 48-inch	48	63	68	72	75	80	84	89
MHHW + 54-inch	54	69	74	78	81	86	90	95
MHHW + 60-inch	60	75	80	84	87	92	96	101

The critical path analysis described in Chapter 3 was also very helpful in highlighting how the exposed areas of the focus areas become inundated or flooded -- either from direct shoreline inundation, or from a critical pathway that can lead to extensive inland inundation. For the Bay Bridge location, this analysis showed that all of inland inundation on the south side of the bridge could be prevented by relatively simple physical strategies (See Appendix B.1: Bay Bridge Focus Area Technical Memorandum (2014), Section 6.2 for examples of these strategies). This allowed creative resources to be focused on developing strategies for the north side of the bridge where water was overtopping broad stretches of the shoreline.

The refined SLR exposure assessments and the rest of the work (data collection and strategy development) were moved forward concurrently due to the time constraints of the project. Ideally the exposure work would be completed before strategy development is underway. For this project, the exposure assessment took longer than expected based on the unforeseen need to field-verify vulnerabilities and re-run the mapping and shoreline analysis at some locations. Although the team had the information needed by the time conceptual design started, time resources were scarce. The time-consuming nature of detailed exposure analysis should not be underestimated.

The coordination between the project and the stakeholder groups being managed by the BCDC project was not ideal due to the projects being on slightly different timeframes. The Consultant Team found that presenting the exposure assessment work completed in each focus area (as soon as it was completed or near completion) to the stakeholder groups was very helpful, and it would have been helpful to have attended all of the stakeholder meetings. The Hayward group in particular seemed to get ahead of the schedule of the rest of the project process, and therefore there could not be an effective feedback loop to inform either project adequately.

9.2.3 ADAPTATION STRATEGY DEVELOPMENT AND EVALUATION

During the project it was decided that at least one adaptation strategy should be developed to address each of the vulnerabilities identified by the project team across the functional, governance, informational and physical categories. Given the number of vulnerabilities identified, this led to an exhaustive approach and the ultimate production of a compendium of 124 adaptation strategies. While it is anticipated that this compendium (see Appendix C) will be a valuable resource for the project partners and other agencies, it may have been better to identify priority vulnerabilities for which to develop a more limited set of adaptation strategies rather than the broad strategy development process that was undertaken. This meant that more time was spent developing a large number of adaptation strategies with limited detail rather than fewer strategies to a much greater detail. There are clearly different approaches to carrying out vulnerability assessments and strategy development processes which will be favored by different agencies. BCDC for example has a strong preference for identifying all vulnerabilities of all assets prior to strategy development, and considering all potential strategies to address those before honing in on strategies to develop in more detail.

Given the large number of strategies developed, a two stage evaluation process was required in order to be able to narrow down the strategies to a final 4 (ultimately 5) to be further developed. Given the number of strategies to be evaluated, a qualitative list of questions was developed for the first stage through which the124 strategies could be run fairly quickly. The second stage involved a slightly more rigorous qualitative assessment, using data collected earlier in the project but not necessarily calculating further numbers. However, even this second stage assessment was not as detailed as the original evaluation process that was envisaged by the client team at the start of the project due to lack of appropriate data at this level of strategy development, particularly on costs and mobility impacts.

The team spent considerable time developing an appropriate set of questions for each stage and carrying out the 2 assessments. Ultimately the technical team over-ruled some of the conclusions reached through the evaluation process for selecting the final strategies for detailed analysis due to specific local knowledge of the assets or strategies under consideration and due to the desire to have at least one strategy in each focus area, and to have a number of the different types of vulnerability addressed. While a standardized qualitative assessment can be a good way to evaluate the performance of strategies, it should always be supplemented by the local knowledge and expertise of stakeholders and agencies.

Finally, the full set of evaluation criteria developed was only used for the final five strategies developed, and given that these strategies were addressing different assets in different locations, the results have more limited use as they cannot really be directly compared.

10.0 Next Steps

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10. NEXT STEPS

This report has significantly enhanced the understanding of the vulnerability of certain key assets in Alameda County to sea level rise inundation across a range of scenarios. It has also proposed a number of representative strategies to help reduce these vulnerabilities that could be applicable to other areas of Alameda County as well as the wider Bay Area and beyond.

A number of the strategies (*SR 92 drainage study* and *Mainstreaming Climate Risk into Transportation Agencies*) could be taken forward now with little further research by appropriate agencies, and this report provides strong evidence to support the funding of these activities.

The physical strategies will all require further analysis and design work to ensure they are the most appropriate solutions to address future flooding from SLR and other extreme weather events at the identified sites. In addition, these strategies could also be considered for potential use at other areas along the Bay shoreline. This report can be used to support funding applications for such analysis. Recommended next steps for each of the focus area strategies are included in their respective chapters (5 and 6).

The compendium of 124 strategies should be reviewed by the agencies, and strategies adopted that could be relatively easily incorporated into existing day-to-day practice (such as updating of design standards in relation to waterproof sealant). Other high-scoring strategies should be identified for further analysis. There were several informational strategies most notably the one on addressing the lack of understanding of the impact of saltwater intrusion on infrastructure, for which assistance from local (or national) academia is needed. Efforts should be made to engage with potential universities and funders of such research such as the USGS.

The report also identified a number of studies being undertaken by other agencies in the County that could improve understanding of the vulnerability of assets, such as the Alameda County Flood Control and Water Conservation District's updated HEC-RAS modelling for Damon Slough, which would improve the riverine flooding analysis of the Coliseum Focus Area. The progress of these studies and analyses should be tracked so that this update can happen in a timely manner.

Finally, the findings from this study, particularly in relation to vulnerable transportation assets and inundation flow paths, should be used to inform decisions regarding the 2017 update of the Bay Area's Sustainable Communities Strategy, Plan Bay Area.

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APPENDICES

Climate Change and Extreme Weather Adaptation Options

for Transportation Assets in the Bay Area Pilot Project

Technical Report • December 2014

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Appendix A

Data Collection Survey Questions

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MTC Test Survey

1. Survey Overview

This survey supports data collection and other critical information for the MTC Climate Change and Extreme Weather Vulnerability Assessment. The study team will use your responses to help assess asset vulnerability and evaluate adaptation measures.

The survey includes questions related to both focus area assets (e.g. SR-92 between Clawiter Road and toll plaza, Interpretive Center, etc.), and up to three individual components of those assets (e.g. power system, toll gates, etc.).

Asset-level questions are included on pages 1 through 6 of the survey. Component #1 questions are on page 8 and 9. These questions are repeated for components #2 and #3 on pages 10 to 13.

If the asset is not made up of components, or there are fewer than 3 individual components, respondents will simply leave answers blank.

The asset and component survey questions are organized into 5 sections:
A. Management and jurisdiction;
B. Physical and location characteristics;
C. Capacity and use; and
D. Expected consequences of disruption.

Please enter your contact information before starting.

***1. What is your name(s)? If more than one person contributed, please list all names.**

***2. What organzation are you associated with?**

***3. What is your job title or role in your organization?**

***4. Email**

***5. Phone number:**

6. Who should we contact with follow up questions or data requests? Please provide contact information.

MTC Test Survey

2. ASSET LEVEL: Management and jurisdiction

Management questions help determine whether an asset or asset category is vulnerable due to challenges with management, regulation, or funding.

*1. What is the name of the asset for which you are providing information? Information in the parenthesis includes the study focus area and whether it is a "core" or "key adjacent" asset.

- SR92 (Hayward - Core)
- Bay Trail (Hayward - Core)
- Hayward Shoreline Interpretive Center (Hayward - Adjacent)
- Oliver Salt Ponds (Hayward - Adjacent)
- Eden Landing Ecological Reserve (Hayward - Adjacent)
- Industrial land uses west of Industrial Blvd (Hayward - Adjacent)
- I-880 from Coliseum Way to 98th Ave. (Coliseum - Core)
- Amtrak Station (Coliseum - Core)
- BART Station (Coliseum - Core)
- BART Oakland Airport Connector (Coliseum - Core)
- MLK Regional Shoreline, E.Creek to Arrowhead Marsh (Coliseum - Adjacent)
- San Leandro Channel (Coliseum - Adjacent)
- Edgewater Droive commerical/industrial (Coliseum - Adjacent)
- San Leandro Street (Coliseum - Adjacent)
- Colesium Arena Complex (Coliseum - Adjacent)
- I-880 from 7th St to 40th St. (Bay Bridge Touch Down - Core)
- I-80 from 40th Street to Powell St. (Bay Bridge Touchdown - Core)
- 7th Street (Bay Bridge Touch Down - Core)
- Eastshore State Park / Emeryville Crescent (Bay Bridge Touch Down - Adjacent)
- EBMUD Main Wastewater Treatment Plant (Bay Bridge Touch Down - Adjacent)
- Burma Rd. Caltrans maintenance and operations facilities (Bay Bridge Touch Down - Adjacent)
- Burma Rd. EBMUD Dechlorination and Discharge Facilities (Bay Bridge Touch Down - Adjacent)
- Burma Rd. Electrical Substation (Bay Bridge Touch Down - Adjacent)
- Burma Rd. Port Operations (Bay Bridge Touch Down - Adjacent)
- West Oakland Track Portal (Bay Bridge Touch Down - Adjacent)

2. If there is a specific asset identifier (such as a code) please provide that identifier.

3. Please describe the geographic area or extent of the asset. For example, what do you consider the boundaries of the asset? You can use streets, mileposts, or other geographic areas to define the asset.

4. Please describe the asset or asset system.

Include definition of asset components including electrical or mechanical components if any, NBI numbers, and other applicable information.

5. Classify the transportation mode for the asset

- [ ] pedestrian
- [ ] bike
- [ ] bus
- [ ] automobile
- [ ] truck only
- [ ] passenger rail
- [ ] freight rail
- [ ] air

Other (please specify)

6. Who owns the asset or asset system?

- Amtrak
- State Parks
- Caltrans
- City
- EBMUD
- BART
- Union Pacific

If city, please specify, and/ or describe other owners.

7. Is the asset owner different than the property owner?

- Yes
- No

Other (please specify)

8. Who owns the property where the asset is located?

- Federal
- State Parks
- Caltrans
- City
- County
- BART
- Union Pacific

Other (please specify)

9. What is the relationship between the asset owner and the property owner?

10. Is there a right-of-way, access easement, or other agreement (e.g., lease)?

- ◯ NA
- ◯ short term lease
- ◯ long term lease
- ◯ right of way
- ◯ easement

Other (please specify)

11. If the asset is part of an interconnected physical system, how are the assets connected (e.g., segment of road or rail connected to other segments, stations connected to track, etc.)?

12. What is the relationship between the asset manager and the manger(s) of interconnected infrastructure (e.g. different departments of the same agency; different agencies with no formal relationship, etc.)?

13. If the asset is protected from flooding by land or assets owned by other entities, what kind of asset provides the protection (e.g., levee)?

14. In instances where other individuals or organizations own or operate assets that protect the asset in question, what is the relationship between the asset owner and the other entities?

15. In instances where other individuals or organizations own or operate assets that protect the asset in question, do organizations coordinate and share information and decision-making?

16. What are the estimated annual operations and maintenance costs for the asset or asset system? Please enter a value in the comment box or enter a range. (e.g. $500K - $1M).

If this information is not available for an asset system, please see component sections.

Cost:

Units (e.g. 2013 dollars per year):

Data source (e.g. Agency Annual Report, 2012):

17. What are the short term (1 to five years) planned annual capital improvement costs for the asset or asset system?

Cost:

Unit (e.g. 2013 dollars per year):

Data source (e.g. Agency Annual Report, 2012):

18. Has the asset experienced a service disruption without structural damage (e.g. extreme weather, etc.)?

- [ ] n/a
- [ ] flooding
- [ ] electric outage
- [ ] earthquake damage
- [ ] planned construction or maintenance

Other (please specify)

19. How frequently has the asset experienced disruptions? Every:

- ○ 0-2 years
- ○ 2-5 years
- ○ 5-10 years
- ○ 10-20 years
- ○ 20 + years

Other (please specify)

20. In what year did the asset last experience a significant disruption?

21. What was the physical extent and nature of the disruption?

22. What has been the time duration of disruption due to these events?

- 1 day or less
- 1 week
- 1 month
- 2-6 months
- 6-12 months
- 1 year +

Other (please specify)

23. What were the estimated costs to the asset owner due to disruption?

If quantified in dollars, please provide. If you do not have an exact value but have an approximate estimate, please enter a range (e.g. $500K - $1M).

If quantified in other ways (staff hours, direct and indirect economic costs, etc) please provide information.

Cost:

Unit (e.g. 2013 dollars):

Data source (e.g. Agency Annual Report, 2012):

24. If the structure was damaged in the disruption, what were the asset manager's costs to repair the asset?

If you do not have an exact value but have an approximate estimate, please enter a range (e.g. $500K - $1M).

Cost:

Unit (e.g. 2013 dollars):

Data source (e.g. Agency Annual Report, 2012):

25. If the asset were damaged, what would the cost be to rebuild in place to current codes and standards? If you do not have an exact value but have an approximate estimate, please enter a range (e.g. $500K - $1M).

26. Which agencies have regulatory authority over the asset?

27. What types of permits are necessary to make changes to the asset?

28. Compared to average time to complete regulatory requirements for similar types of assets, how long does it take to satisfy regulatory requirements?

29. Are there regulatory conflicts that might impede or prevent actions or proposals to adapt to sea level rise?

- ◯ Yes
- ◯ No

If yes, please describe any regulatory conflicts:

30. Describe any plans that are relevant to asset management or improvement (e.g., Master Plan, Capital Improvement Plan, etc.). Please include the name of the plan, the last update and the next update.

31. Describe data management systems that are in place that help the organization manage its assets.

32. Is the asset currently under consideration for improvement, or is it in an area that is planned for future development / redevelopment?

- ◯ Yes
- ◯ No

If yes, please describe:

3. ASSET LEVEL: Vulnerability Information Metrics

Information metrics help determine whether there are any ways in which an asset or asset category is vulnerable due to lacking, incomplete, or poorly coordinated information.

1. What types of information sources necessary to conduct a vulnerability and risk assessment are availableto the asset manager? Is the data publicly available? What is the quality level?

	Not available	Available to asset manager	Publicly available	High quality	Low quality	Sufficient for decision-making
Databases with asset owner and manager	☐	☐	☐	☐	☐	☐
Condition and elevation of assets (e.g. roads, rail, transit)	☐	☐	☐	☐	☐	☐
Georeferenced (GIS) data	☐	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐	☐

If you checked boxes for "other" please define what other data you are qualifying.

4. ASSET LEVEL: Physical characteristics

Physical characteristics metrics help determine whether an asset or asset category has vulnerabilities due to how an asset is designed or built.

1. Is the asset in the current 100-year floodplain?

- ○ Yes
- ○ No

Other (please specify)

2. Is the asset subject to failure or capacity loss due to inundation depths associated with the 100 year event?

- ○ Yes
- ○ No

Other (please specify)

3. Does the asset cross tidal creeks or the Bay?

- ○ Yes
- ○ No

Other (please specify)

4. How old is the asset? Please provide the year of construction.

5. In what year did the asset undergo its most recent major reconstruction.

6. In what year is the asset scheduled to be replaced?

7. What is the current condition of the asset?

- ◯ Excellent
- ◯ Good
- ◯ Fair
- ◯ Poor

Other (please specify)

8. If the asset is a bridge, is it classified as scour critical?

- ◯ Yes
- ◯ No

Other (please specify)

9. Are any components of the asset that are at-grade or below-grade (e.g., tubes, tunnels, ventilation grates, switchgears, electrical or mechanical components) waterproof, corrosion-resistant, or otherwise protected from water?

- ◯ Yes
- ◯ No

Other (please specify)

10. If components or parts of the asset are below-grade, which components or parts?

- ☐ tubes
- ☐ tunnels
- ☐ ventilation grates
- ☐ switchgears
- ☐ electrical or mechanical components

Other (please specify)

11. Does the asset include electrical/mechanical elements that are sensitive to saltwater?

- Yes
- No

Other (please specify)

12. If yes to the question above, which elements of the asset?

13. Are such elements susceptible to saltwater intrusion?

- Yes
- No

Other (please specify)

14. Are resources sufficient to maintain highest targeted maintenance schedule and condition?

- Yes
- No

If no, please explain:

15. Could the asset be reengineered to reduce vulnerability (rather than protection or other adaptation)?

- Yes
- No

If yes, please explain:

16. How many people work at the asset on a typical work day?

17. Can the asset function if they are unable to report to work?

- ◯ Yes
- ◯ No

If yes, for how long?

18. How much power does the asset consume?

Amount:

Unit (e.g. annual kWh):

Data source:

19. How is power delivered to the asset?

20. What happens if supply of power is interrupted?

21. How much water does the asset consume?

Amount:

Unit (e.g. gallons per day):

Data source:

22. How is water delivered to the asset?

23. What happens if the supply of water is interrupted?

24. How much waste is produced?

Amount:

Unit (e.g. tons per day)

Data source:

25. If there is waste, how is it removed?

26. What happens when waste cannot be removed?

27. Are there any groundwater monitoring wells or groundwater level data available for the asset or nearby area?

- ◯ Yes
- ◯ No

Other (please specify)

28. If saltwater intrusion into the water table is currently a problem, please describe.

29. Can an elevated water table or saltwater intrusion could cause problems for the asset?

- ◯ Yes
- ◯ No

Other (please specify)

30. Are assets or part of the asset system in an area with high seismic susceptibility and/or liquefaction potential?

- ◯ Yes
- ◯ No

Other (please specify)

MTC Test Survey

31. Please describe seismic retrofit, either planned or completed.

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5. ASSET LEVEL: Functional characteristics

Functional characteristics metrics help determine whether an asset or asset category is vulnerable due to its functions and relationships with other assets and asset categories.

1. What is the current level of use of the asset? Please provide data for all that apply.

AADT

Truck AADT

Annual ridership

Annual US tons of cargo

Annual TEU

Annual value of goods shipped

Other (specify)

2. Please provide the analysis year for each data point above.

AADT

Truck AADT

Annual ridership

Annual US tons of cargo

Annual TEU

Annual value of goods shipped

Other (specify)

3. What was the source for the data above (e.g. Agency Annual Report, 2012)? Please list as many as apply.

AADT

Truck AADT

Annual ridership

Annual US tons of cargo

Annual TEU

Annual value of goods shipped

Other (specify)

MTC Test Survey

4. What is the estimated future level of use?

AADT

Truck AADT

Annual ridership

Annual US tons of cargo

Annual TEU

Annual value of goods shipped

Other (specify)

5. Please note the analysis year for the data above:

AADT

Truck AADT

Annual ridership

Annual US tons of cargo

Annual TEU

Annual value of goods shipped

Other (specify)

6. What was the source for the forecast data above (e.g. Agency Annual Report, 2012)? Please list as many as apply.

AADT

Truck AADT

Annual ridership

Annual US tons of cargo

Annual TEU

Annual value of goods shipped

Other (specify)

7. What is the peak period factor, if any?

8. In what unit (e.g. daily 2-hr to annual)?

9. How does the facility perform currently? Please note analysis year(s).

Level of service

Volume to capacity

Vehicle hours of delay

Travel time index (reliability)

Other

10. How is it estimated to perform in the future? Please note the analysis year(s).

Level of service

Volume to capacity

Vehicle hours of delay

Travel time index (reliability)

Other

11. Does the asset provide access to other critical regional assets?

- Airport
- Seaport
- Other

Other (please specify)

12. Redundant facilities: Are there critical trips that could not reasonably be completed if this asset were to fail? Please explain.

- Yes
- No

Please explain

13. Are redundant facilities generally subject to similar failure modes?

- Yes
- No

Other (please specify)

14. For bridges, what is the NBI detour distance?

15. For assets that rely on power to function such as electrified rail, are there resilient or alternative power supplies (e.g., generator with sufficient fuel and protected from weather event impacts)?

- Yes
- No

Other (please specify)

16. Is the asset a sole or limited access route?

- NA
- Yes
- No
- Don't Know

17. Is the asset an emergency or lifeline route?

- NA
- Yes
- No
- Don't Know

18. Does the asset currently serve transit-dependent populations?

- NA
- Yes
- No
- Don't Know

Other (please specify)

19. Please note reference source regarding transit-dependent community.

20. Does the asset include a goods movement route?

- NA
- Yes
- No
- Don't Know

Other (please specify)

21. Would failure of one part of the asset disrupt the entire interconnected transportation system?

- NA
- Yes
- No
- Don't Know

Other (please specify)

6. ASSET LEVEL: Consequences of Climate Change

1. Does the asset serve critical public health related facilities?

- [ ] hospital
- [ ] medical clinic
- [ ] fire station
- [ ] police station;
- [ ] school
- [ ] none
- [ ] other

Other (please specify)

2. Does the asset serve socially vulnerable communities? Please describe issues not addressed in "transit-dependent population" questions.

3. Please note reference source regarding this community.

4. If there are hazardous materials at the asset site, could they be moved in floodwater?

5. If there are hazardous materials, how close are they to sensitive receptors (e.g., schools, elderly housing, hospitals)? Please note the approximate distance in miles to the receptors listed below.

Hospital or medical clinic

Fire station

Police station

School

Low-income disadvantaged

Low mobility

Transit dependent

Other (please describe receptor)

6. What is the data source for the hazardous material information (e.g. Agency Annual Report, 2012)?

7. Does the asset provide public access to the shoreline or other recreational opportunities?

- Yes
- No

Other (please specify)

8. If the asset were disrupted, damaged, or under construction (repair) how would it affect adjacent natural areas?

9. If the asset were disrupted, damaged or under construction (repair) what hazardous materials could pose a risk to public health?

10. What is the value of the asset to the local economy? Does it contribute to major economic activity or employment centers, generate revenue, provide jobs, etc.?

11. Are there sunk costs in the asset? That is, have new investments been made in the asset that would be lost if rebuilding or relocating were necessary?

12. What is the scale of economic costs if the asset were to experience service disruptions or damage? Would they be local, regional, state, or federal?

7. Component - level survey

The following three sections collect information and data about individual components of the asset described in the preceding section. Please describe up to three key components. The survey will ask the full set of questions for component one, followed by the set of questions for components two and three. If there are more than three components, a member of the team will follow up with you to collect information.

1. Do you have more than 3 components related to the preceding asset to describe? If yes, a member of the study team will contact you using information provided on the first page.

- ◯ NA
- ◯ Yes
- ◯ No

Other (please specify)

8. COMPONENT 1: Management and jurisdiction

***1. What is the name of the component?**

2. Please describe the component.

Include a definition of the component including extent, location, function, and other information about relevant parts of the component (e.g. electrical, mechanical, etc.)

3. Please identify the name, owner, and location of a component map and/or schematic, if available for this study.

4. What are the average annual ongoing operations and maintenance costs for the component or component system?

If you do not have an exact value but have an approximate estimate, please enter a range (e.g. $500K - $1M).

Average annual operations and maintenance cost:

Unit of measure (e.g. per mile):

Data source (e.g. Agency Annual Report, 2012):

5. Has the component experienced a service disruption without structural damage (e.g. extreme weather, labor strike, etc.)?

- [ ] NA
- [ ] flooding
- [ ] electric outage
- [ ] earthquake damage
- [ ] planned construction or maintenance

Other (please specify)

6. How frequently has the component experienced disruptions?

- ( ) NA
- ( ) 0-2 years
- ( ) 2-5 years
- ( ) 5-10 years
- ( ) 10-20 years
- ( ) 20+ years

Other (please specify)

7. In what year did the component last experience a significant disruption?

8. If the component experienced disruption, what was the physical extent and nature of the disruption?

9. If the component experienced disruption, what was the time duration?

- ◯ NA
- ◯ Less than 1 day
- ◯ 1 day
- ◯ 1 week
- ◯ 1 month
- ◯ 2-3 months
- ◯ 4-6 months
- ◯ 6-12 months
- ◯ longer than 1 year

Other (please specify)

10. What were the estimated costs to the component owner due to disruption?

If quantified in dollars, please provide.
If quantified in other ways (staff hours, direct and indirect economic costs, etc) please provide information.

Estimated total cost:

Scale of cost (e.g. gross regional product, direct agency expenditure):

Unit of measure (e.g. 2013 dollars)

Source (e.g. Agency Annual Report, 2012):

Other (please specify):

11. Has the component been damaged or lost function in the past?

- ☐ NA
- ☐ Yes
- ☐ No

Other (please specify)

12. If the component has been damaged, in what year did the component last experience significant damage?

13. If the component was damaged, what was the extent and nature of the damage?

14. If the component was damaged, what were the component manager's costs to repair the component?

Costs to repair:

Unit of measure (e.g. 2013 dollars, 2013 dollars per mile, etc.)

Data source (e.g. Agency Annual Report, 2012)

Other

15. If the component were damaged, what would the cost be to rebuild in place to current codes and standards?

If you do not have an exact value but have an approximate estimate, please enter a range (e.g. $500K - $1M).

16. What types of permits are necessary to make changes to the component? List any that are relevant.

17. Compared to average time to complete regulatory requirements for similar types of components, how long does it take to satisfy regulatory requirements?

9. COMPONENT 1: Physical Characteristics

1. Is the component in the 100-year floodplain?

- NA
- Yes
- No

Other (please specify)

2. Is the component subject to failure or capacity loss due to inundation depths associated with the 100 year event?

- NA
- Yes
- No

Other (please specify)

3. Does the component cross tidal creeks or the Bay?

- NA
- Yes
- No

Other (please specify)

4. How old is the component?

5. What is the current condition of the component?

6. In what year is the component scheduled to be replaced?

MTC Test Survey

7. Are any elements of the component that are at-grade or below-grade (e.g., tubes, tunnels, ventilation grates, switchgears) waterproof, corrosion-resistant, or otherwise protected from water?

8. If component parts are at-grade or below-grade, which parts?

9. Does the component include electrical/mechanical parts that are sensitive to saltwater?

- NA
- Yes
- No

Other (please specify)

10. If the component includes parts sensitive to salt water, which parts?

11. If the component includes parts sensitive to salt water, are these parts susceptible to saltwater intrusion?

12. Are resources sufficient to maintain highest maintenance schedule and condition? Please explain.

13. Could the component be re-engineered to reduce vulnerability (rather than protection or other adaptation)? Please describe.

14. How much power does the component consume?

Amount:

Unit (e.g. annual kWh):

Source:

15. How is power delivered to the component?

16. What happens if electricity supply to the component is interrupted?

17. How much water does the component consume?

Amount:

Units (e.g. gallons per hour):

Source:

18. If the component consumes water, how is it delivered to the component?

19. What happens if water supply is interrupted?

20. How much waste is produced by the component, if any?

Amount:

Unit (e.g. tons)

Data source:

21. How is waste removed, if any?

22. What happens when waste can not be removed?

23. Are there any groundwater monitoring wells or groundwater level data available for the component or nearby area?

- ◯ NA
- ◯ Yes
- ◯ No

Other (please specify)

24. If saltwater intrusion into the water table is currently a problem, please describe.

25. Can an elevated water table or saltwater intrusion cause problems for the component? If yes, please describe.

26. Describe seismic retrofit for the component, either planned or completed.

27. Would failure of one part of the component disrupt the entire interconnected transportation system? Please describe.

10. COMPONENT 2: Management and jurisdiction

***1. What is the name of the component?**

2. Please describe the component.

Include a definition of the component including extent, location, function, and other information about relevant parts of the component (e.g. electrical, mechanical, etc.)

3. Please identify the name, owner, and location of a component map and/or schematic, if available for this study.

4. What are the average annual ongoing operations and maintenance costs for the component or component system?

If you do not have an exact value but have an approximate estimate, please enter a range (e.g. $500K - $1M).

Average annual operations and maintenance cost:

Unit of measure (e.g. per mile):

Data source (e.g. Agency Annual Report, 2012):

5. Has the component experienced a service disruption without structural damage (e.g. extreme weather, labor strike, etc.)?

- ☐ NA
- ☐ flooding
- ☐ electric outage
- ☐ earthquake damage
- ☐ planned construction or maintenance

Other (please specify)

6. How frequently has the component experienced disruptions?

- ○ NA
- ○ 0-2 years
- ○ 2-5 years
- ○ 5-10 years
- ○ 10-20 years
- ○ 20+ years

Other (please specify)

7. In what year did the component last experience a significant disruption?

8. If the component experienced disruption, what was the physical extent and nature of the disruption?

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- ◯ NA
- ◯ Less than 1 day
- ◯ 1 day
- ◯ 1 week
- ◯ 1 month
- ◯ 2-3 months
- ◯ 4-6 months
- ◯ 6-12 months
- ◯ longer than 1 year

Other (please specify)

10. What were the estimated costs to the component owner due to disruption?

If quantified in dollars, please provide.
If quantified in other ways (staff hours, direct and indirect economic costs, etc) please provide information.

Estimated total cost:

Scale of cost (e.g. gross regional product, direct agency expenditure):

Unit of measure (e.g. 2013 dollars)

Source (e.g. Agency Annual Report, 2012):

Other (please specify):

11. Has the component been damaged or lost function in the past?

- ☐ NA
- ☐ Yes
- ☐ No

Other (please specify)

12. If the component has been damaged, in what year did the component last experience significant damage?

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14. If the component was damaged, what were the component manager's costs to repair the component?

Costs to repair:

Unit of measure (e.g. 2013 dollars, 2013 dollars per mile, etc.)

Data source (e.g. Agency Annual Report, 2012)

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11. COMPONENT 2: Physical Characteristics

1. Is the component in the 100-year floodplain?

- NA
- Yes
- No

Other (please specify)

2. Is the component subject to failure or capacity loss due to inundation depths associated with the 100 year event?

- NA
- Yes
- No

Other (please specify)

3. Does the component cross tidal creeks or the Bay?

- NA
- Yes
- No

Other (please specify)

4. How old is the component?

5. What is the current condition of the component?

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- Yes
- No

Other (please specify)

10. If the component includes parts sensitive to salt water, which parts?

11. If the component includes parts sensitive to salt water, are these parts susceptible to saltwater intrusion?

12. Are resources sufficient to maintain highest maintenance schedule and condition? Please explain.

13. Could the component be re-engineered to reduce vulnerability (rather than protection or other adaptation)? Please describe.

MTC Test Survey

14. How much power does the component consume?

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Unit (e.g. annual kWh):

Source:

15. How is power delivered to the component?

16. What happens if electricity supply to the component is interrupted?

17. How much water does the component consume?

Amount:

Units (e.g. gallons per hour):

Source:

18. If the component consumes water, how is it delivered to the component?

19. What happens if water supply is interrupted?

20. How much waste is produced by the component, if any?

Amount:

Unit (e.g. tons)

Data source:

21. How is waste removed, if any?

22. What happens when waste can not be removed?

23. Are there any groundwater monitoring wells or groundwater level data available for the component or nearby area?

- ◯ NA
- ◯ Yes
- ◯ No

Other (please specify)

24. If saltwater intrusion into the water table is currently a problem, please describe.

25. Can an elevated water table or saltwater intrusion cause problems for the component? If yes, please describe.

26. Describe seismic retrofit for the component, either planned or completed.

27. Would failure of one part of the component disrupt the entire interconnected transportation system? Please describe.

12. COMPONENT 3: Management and jurisdiction

***1. What is the name of the component?**

2. Please describe the component.

Include a definition of the component including extent, location, function, and other information about relevant parts of the component (e.g. electrical, mechanical, etc.)

3. Please identify the name, owner, and location of a component map and/or schematic, if available for this study.

4. What are the average annual ongoing operations and maintenance costs for the component or component system?

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Average annual operations and maintenance cost:

Unit of measure (e.g. per mile):

Data source (e.g. Agency Annual Report, 2012):

5. Has the component experienced a service disruption without structural damage (e.g. extreme weather, labor strike, etc.)?

- ☐ NA
- ☐ flooding
- ☐ electric outage
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- ☐ planned construction or maintenance

Other (please specify)

6. How frequently has the component experienced disruptions?

- ○ NA
- ○ 0-2 years
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Other (please specify)

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9. If the component experienced disruption, what was the time duration?

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- ◯ 1 month
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- ◯ 6-12 months
- ◯ longer than 1 year

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10. What were the estimated costs to the component owner due to disruption?

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Estimated total cost:

Scale of cost (e.g. gross regional product, direct agency expenditure):

Unit of measure (e.g. 2013 dollars)

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Other (please specify):

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- ☐ Yes
- ☐ No

Other (please specify)

12. If the component has been damaged, in what year did the component last experience significant damage?

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Data source (e.g. Agency Annual Report, 2012)

Other

15. If the component were damaged, what would the cost be to rebuild in place to current codes and standards?

If you do not have an exact value but have an approximate estimate, please enter a range (e.g. $500K - $1M).

16. What types of permits are necessary to make changes to the component? List any that are relevant.

17. Compared to average time to complete regulatory requirements for similar types of components, how long does it take to satisfy regulatory requirements?

13. COMPONENT 3: Physical Characteristics

1. Is the component in the 100-year floodplain?

- NA
- Yes
- No

Other (please specify)

2. Is the component subject to failure or capacity loss due to inundation depths associated with the 100 year event?

- NA
- Yes
- No

Other (please specify)

3. Does the component cross tidal creeks or the Bay?

- NA
- Yes
- No

Other (please specify)

4. How old is the component?

5. What is the current condition of the component?

6. In what year is the component scheduled to be replaced?

7. Are any elements of the component that are at-grade or below-grade (e.g., tubes, tunnels, ventilation grates, switchgears) waterproof, corrosion-resistant, or otherwise protected from water?

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- Yes
- No

Other (please specify)

10. If the component includes parts sensitive to salt water, which parts?

11. If the component includes parts sensitive to salt water, are these parts susceptible to saltwater intrusion?

12. Are resources sufficient to maintain highest maintenance schedule and condition? Please explain.

13. Could the component be re-engineered to reduce vulnerability (rather than protection or other adaptation)? Please describe.

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Unit (e.g. annual kWh):

Source:

15. How is power delivered to the component?

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Amount:

Units (e.g. gallons per hour):

Source:

18. If the component consumes water, how is it delivered to the component?

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20. How much waste is produced by the component, if any?

Amount:

Unit (e.g. tons)

Data source:

21. How is waste removed, if any?

22. What happens when waste can not be removed?

23. Are there any groundwater monitoring wells or groundwater level data available for the component or nearby area?

- ◯ NA
- ◯ Yes
- ◯ No

Other (please specify)

24. If saltwater intrusion into the water table is currently a problem, please describe.

25. Can an elevated water table or saltwater intrusion cause problems for the component? If yes, please describe.

26. Describe seismic retrofit for the component, either planned or completed.

27. Would failure of one part of the component disrupt the entire interconnected transportation system? Please describe.

14. Thank you!

This concludes the Bay Area Climate Change and Extreme Weather Vulnerability Assessment data collection survey. Thank you for your participation.

Appendix B

Vulnerability Refinement Technical Memoranda

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Memorandum

To	Stefanie Hom (MTC)	Page	1
CC	Wendy Goodfriend (BCDC), Dick Fahey (Caltrans), Norman Wong (BART), Clair Bonham-Carter (AECOM)		
Subject	San Francisco-Oakland Bay Bridge Touchdown Focus Area		
From	Ricky Torres-Cooban, EIT, Michael Mak, P.E., Justin Vandever, P.E., Kris May, Ph.D., P.E.		
Date	June 25, 2014		

1. INTRODUCTION AND PURPOSE

The San Francisco-Oakland Bay Bridge touchdown (Bay Bridge Touchdown) was selected as a focus area for more detailed sea level rise exposure analysis and adaptation strategy development as part of the current Metropolitan Transportation Commission (MTC) Climate Adaptation Pilot Study. Under the precursor MTC Vulnerability and Risk Assessment Project (BCDC et al. 2011), this area was shown to be vulnerable to inundation by sea level rise and coastal storm surge that could impact critical transportation assets and other adjacent assets that support the region, as identified by the Project Management Team (PMT). The purpose of this memorandum is to identify the key areas of vulnerability that exist within the focus area and assess the sources, mechanisms, and timing of inland inundation and flooding to inform the development of adaptation strategies.

This technical memorandum should be considered in tandem with other ongoing work by the San Francisco Bay Conservation and Development Commission (BCDC) and Alameda County Flood Control and Water Conservation District (ACFCWCD) to better understand sea level rise, storm surge, and shoreline vulnerabilities in Alameda County. The following sections provide a description of the Bay Bridge Touchdown Focus Area (Section 2), an assessment of exposure to inundation and flooding (Section 3), identification of key areas of vulnerability (Section 4), recommendations for timing of adaptation measures (Section 5), proposed adaptation measures (Section 6), and conclusions and next steps (Section 7).

2. FOCUS AREA DESCRIPTION

The Bay Bridge Touchdown focus area is located south of Emeryville Marina in the San Francisco Bay (Bay), along the northern boundary of the Oakland Outer Harbor (Figure 1). The area includes the Bay Bridge Touchdown and westbound toll plaza as well as the intersection of interstate highways I-580, I-80, and I-880. The northern portion of the focus area is mostly tidal wetlands with a small area immediately north of the Bay Bridge westbound tollbooths at Radio Beach where three radio towers are located. The core asset in this focus area is the Bay Bridge Touchdown. Several adjacent assets are also located within this focus area south of I-80, including a wastewater discharge transition structure and dechlorination facilities owned and operated by the East Bay Municipal Utility District (EBMUD) at the western tip of the shoreline, the main EBMUD wastewater treatment plant farther inland (to the east), electrical substations, the Port of Oakland, and several other industrial buildings, temporary and permanent, of which some have historical value. The proposed site for Gateway Park is also within this focus area.

The area north of the Bay Bridge Touchdown (Areas A to C in Figure 1) is a tidal wetland and experiences regular tidal inundation under existing conditions. Approximately one third of the shoreline has some degree of rock protection. South of I-80, the Port of Oakland berths 7-10 (Areas G and H in Figure 1) are constructed of concrete and elevated several feet above typical high tides. Along the western portion of the focus area (Areas D to F in Figure 1), engineered rock protection exists along the majority of the shoreline and some tidal inundation occurs under existing conditions in low-lying areas along the shoreline.

The AECOM team performed a site visit on March 7, 2014 with BCDC, MTC, BART, and Caltrans staff. Visual inspection of shoreline protection structures and assets was performed along the northern and southern shorelines of the Bay Bridge touchdown and along Burma Road. Areas subject to tidal inundation under existing conditions were also verified. See Attachment A for site visit photos.

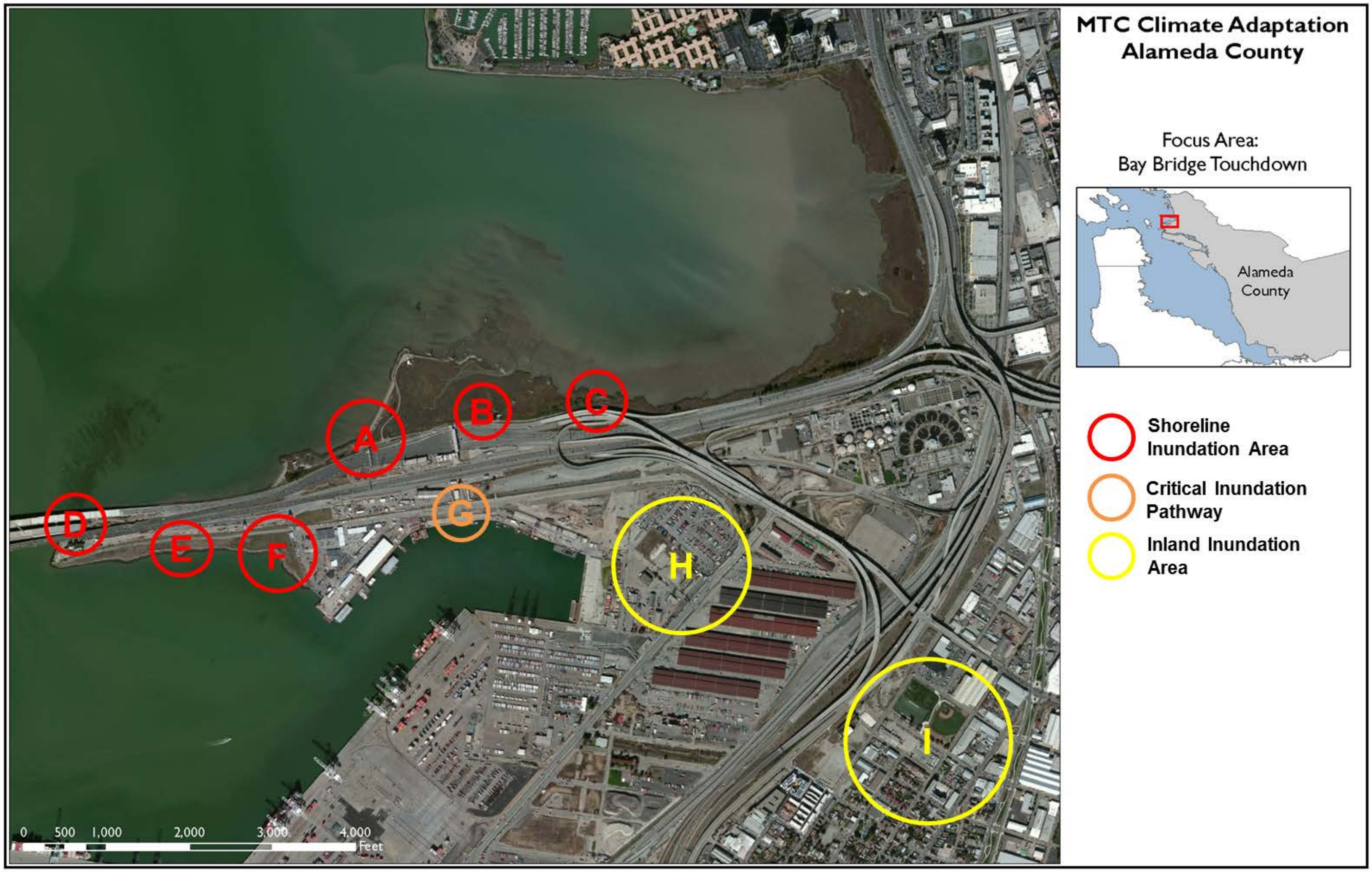

Figure 1. Bay Bridge Touchdown Focus Area Site Location Map and Inundation Areas

Note: Circles are used to indicate approximate locations and extents of inundation. Circle sizes do not correspond to intensity, timing, or risk of inundation.

3. INUNDATION AND FLOODING EXPOSURE

In the discussion that follows, a clear distinction is made between the terms *inundation* and *flooding*. Permanent *inundation* occurs when an area is exposed to regular daily tidal inundation. A permanently inundated area can no longer be used in the same way as an inland area due to the frequency of its exposure to sea water. In contrast, *flooding* occurs when an area is exposed to episodic, short duration, extreme tide events of greater magnitude than normal tide levels. Inland areas may be temporarily flooded during an extreme tidal event while maintaining at least a portion of their functionality once the floodwaters recede. However, sensitive assets may suffer irreversible damage if exposed to any amount of water, even temporarily. The term flooding, as it is used throughout this memorandum, is therefore a temporary inundation condition that results from a storm event rather than the permanent inundation due to daily high tides.

To assess portions of the shoreline that are exposed to inundation and flooding within the Bay Bridge Touchdown focus area, six sea level rise and inundation mapping scenarios were examined (Table 1). Inundation maps were created for each of the scenarios using the methodology developed by the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (Marcy et al. 2011). The scenarios were developed by adding different amounts of sea level rise onto the elevation of the existing conditions daily high tide level (represented by the Mean Higher High Water (MHHW) tide). The MHHW reference water levels used in this analysis were derived from MIKE21 model output from a regional San Francisco Bay modeling study completed as part of the Federal Emergency Management Agency (FEMA) San Francisco Bay Area Coastal Study [1] (DHI 2011). The modeling study spanned a 31-year period from January 1, 1973 to December 31, 2003. The MHHW tidal datum was calculated using the portion of the model output time series corresponding to the most recent National Tidal Datum Epoch (1983 through 2001), which is a specific 19-year period adopted by NOAA to compute tidal datums.

In accordance with the most up-to-date sea level rise projections, the following scenarios were evaluated for the present study: 12-inch, 24-inch, 36-inch, and 48-inch. In addition to these scenarios, 72-inch and 96-inch scenarios were also evaluated; but these water levels are outside the range of current scientific predictions for sea level rise and, therefore, do not correspond with permanent inundation scenarios that are likely to occur before 2100 (NRC 2012). Rather, these scenarios are included to evaluate important extreme flooding scenarios that could happen during storm surge events with lesser amounts of sea level rise. Mapped scenarios are listed in Table 1**.** The inundation maps for this focus area were developed by AECOM as a part of the Alameda County Sea Level Rise Shoreline Vulnerability Assessment for BCDC and ACFCWCD and are shown in Attachment B. The maps show inundation areas and depths as well as overtopping potential lines along the shoreline and the edges of the highway. "Overtopping potential" refers to the condition where the water surface elevation associated with a particular reference water level exceeds the elevation of the shoreline asset. The depth of overtopping potential at each shoreline segment is calculated by taking an average of several depths over the length of the segment. This assessment is considered a planning-level tool only, as it does not account for the physics of wave runup and overtopping. It also does not account for potential vulnerabilities along the shoreline protection infrastructure that could result in

[1] www.r9coastal.org

complete failure of the flood protection infrastructure through scour, undermining, or breach after the initial overtopping occurs.

Table 1. Sea Level Rise Inundation Mapping Scenarios

Mapping Scenario	Reference Water Level	Applicable Range for Mapping Scenario (Reference +/- 3 inches)
Scenario 1	MHHW + 12-inch	MHHW + 9 – 15 inch
Scenario 2	MHHW + 24-inch	MHHW + 21 – 27 inch
Scenario 3	MHHW + 36-inch	MHHW + 33 – 39 inch
Scenario 4	MHHW + 48-inch	MHHW + 45 – 51 inch
Scenario 5	MHHW + 72-inch	MHHW + 69 – 75 inch
Scenario 6	MHHW + 96-inch	MHHW + 93 – 99 inch

It is important to understand that the reference water levels listed for each mapping scenario can occur due to a variety of hydrodynamic conditions by combining different amounts of sea level rise with either a daily[2] or extreme high tide. For example, Scenario 3 (MHHW + 36-inch) represents a water level reached both by daily high tide with 36 inches of sea level rise or a 50-year extreme tide with no sea level rise (i.e., existing conditions). A +/- 3-inch tolerance was added to each reference water level to increase the applicable range of the mapped scenarios. For example, Scenario 3 (MHHW + 36-inch) is assumed to be representative of all extreme tide/sea level rise combinations that produce a water level in the range of MHHW + 33 inches to MHHW + 39 inches. By combining different amounts of sea level rise and extreme tide levels, a matrix of water level scenarios was developed to identify the various combinations represented by each inundation map.

The matrix of sea level rise and tide scenarios is presented in Table 2. Values are shown in inches above the existing conditions MHHW level. The coloring shown matches the coloring in Table 1 and indicates the different combinations of sea level rise and extreme tide scenarios represented by each inundation map. Note that Scenarios 5 and 6 correspond only to extreme tide events as they are outside of the range of projections for probable sea level rise over the next century. The first row of the table shows values for existing conditions. For example, to read Table 2, the inundation map that represents MHHW + 36 inches (Scenario 3), would also represent a 1-yr event with 24 inches of sea level rise, a 2-yr event with 18 inches of sea level rise, a 5-yr event with 12 inches of sea level rise, etc. Equivalent water levels for the MHHW + 12-inch, MHHW + 24-inch, MHHW + 36-inch, MHHW + 48-inch, MHHW + 72-inch, and MHHW + 96-inch mapping scenarios can be determined similarly by tracking the color coding through the table. Alternatively, this matrix could be used to plan for a particular level of risk. For example, to examine infrastructure exposure to a 100-yr extreme tide event with an estimated 6 inches of sea level rise, the MHHW + 48-inch mapping scenario could be examined. Using this approach, it is possible to assign flood risk to assets at various time scales and frequency of flooding.

[2] Mean Higher High Water (MHHW) is used as a surrogate for the average daily high tide. MHHW is the average of the higher high water level of each tidal day observed over the National Tidal Datum Epoch. It should be noted that. The actual higher high tide that occurs on any given day will be higher or lower than MHHW. MHHW is approximately 6.2 ft NAVD88 within this focus area.

Table 2. Matrix of Water Levels Associated with Sea Level Rise and Extreme Tide Scenarios

	Daily Tide	Extreme Tide (Storm Surge)						
Sea Level Rise Scenario	**Water Level above MHHW**	**1-yr**	**2-yr**	**5-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**
Existing Conditions	0	14	19	23	27	33	37	42
MHHW + 6-inch	6	20	25	29	33	39	43	48
MHHW + 12-inch	12	26	31	35	39	45	49	54
MHHW + 18-inch	18	32	37	41	45	51	55	60
MHHW + 24-inch	24	38	43	47	51	57	61	66
MHHW + 30-inch	30	44	49	53	57	63	67	72
MHHW + 36-inch	36	50	55	59	63	69	73	78
MHHW + 42-inch	42	56	61	65	69	75	79	84
MHHW + 48-inch	48	62	67	71	75	81	85	90
MHHW + 54-inch	54	68	73	77	81	87	91	96
MHHW + 60-inch	60	74	79	83	87	93	97	102

Note: All values in inches above existing conditions MHHW at Bay Bridge Touchdown Focus Area. The extreme tide levels above MHHW were derived from the FEMA MIKE 21 model output. Color coding indicates which combinations of sea level rise and extreme tides are represented by the mapping scenarios shown in Table 1. Cells with no color coding do not directly correspond to any of the mapping scenarios shown in Table 1.

4. KEY AREAS OF VULNERABILITY

By combining the information available in the water level matrix (Table 2) with the results of the inundation mapping and overtopping potential calculations, shoreline exposure to inundation/flooding and the timing of exposure can be evaluated. This study identified nine key areas of vulnerability within the Bay Bridge Touchdown focus area based on the results of the inundation mapping. Timing of inundation and proximity to important assets were the fundamental criteria used to select these areas, which are identified in Figure 1 and labeled letters "A" through "I". These areas can be grouped into three categories -- *shoreline inundation areas*, *critical inundation pathways*, and *inland inundation areas*. In Figure 1, shoreline inundation areas (A-F) are labeled in red, critical inundation pathways (G) in orange, and inland inundation areas (H-I) in yellow.

Shoreline inundation areas are immediately adjacent to the shoreline and are both the most vulnerable to flooding and the most likely to experience permanent inundation as a result of sea level rise. These areas are where the shoreline is first overtopped and from which floodwaters will propagate to areas immediately inland[3]. Six shoreline inundation areas were identified for the Bay Bridge Touchdown focus area and are discussed in Section 4.1. *Inland* inundation areas are not directly on the shoreline and require a hydraulic pathway to convey floodwaters from the Bay to the inland area. These areas are the least likely to experience the full extent of temporary flooding depicted in the inundation maps due to the typical duration of a coastal storm surge event and volume of water that would be required to fill these expansive low-lying areas during an episodic event. To determine the exact extent of inland flooding or permanent inundation, more sophisticated modeling is required; however, the exposure of these areas to potential inundation and flooding is well represented by the inundation maps for the purposes of this study. Two inland inundation areas were identified within the Bay Bridge Touchdown focus area and are discussed in Section 4.3. Critical inundation pathways connect shoreline inundation areas to the inland inundation areas, providing the necessary hydraulic connectivity to convey floodwaters to inland areas. One critical inundation pathway was identified within the Bay Bridge Touchdown focus area and is discussed in Section 4.2.

4.1 SHORELINE INUNDATION AREAS

Six shoreline inundation areas were identified within the Bay Bridge Touchdown focus area (See Figure 1). Extensive shoreline inundation occurs in the earliest mapped scenario (MHHW + 12-inch); and inundated areas primarily include the tidal wetlands north of the Bay Bridge Touchdown and the radio towers located adjacent to Radio Beach (Areas A-C). The northernmost highway lane as well as the access road immediately adjacent to the toll plaza are partially inundated in the 12-inch and 24-inch scenarios though only with minimal inundation depths and limited extents. Critical portions of the westbound highway assets are extensively inundated at the 36-inch scenario. Access roads in both the northern and southern portions of the Bay Bridge touchdown are also extensively inundated at the

[3] The sea level rise scenario when the site is first overtopping has been approximated based on the mapped sea level rise inundation scenarios (e.g., 12", 24", 36", 48"). The actual sea level rise scenario which results in overtopping may be less than this amount (i.e., if the SLR scenario of first overtopping is 36 inches, overtopping is first observed in this mapped scenario, but overtopping may occur as early as 25 inches). Refined shoreline tools have been developed for this area that can estimate the overtopping threshold within 6 inch increments, and these tools can be used for future updates to this assessment.

36-inch scenario. Additionally, partial inundation of the southwestern tip of the peninsula (Area D) endangers electrical and wastewater treatment facilities at the 36-inch scenario. Inundation maps for the 36-inch scenario are shown in Figure 2 and Figure 3. The six shoreline inundation areas are summarized below:

- Area A (Figure 2)
  - Limited inundation occurs near the toll plaza as early as 12-inch scenario
  - Inundation of the westbound highway lanes first occurs at the 36-inch scenario with inundation depths of 0-3 feet

- Area B (Figure 2)
  - Limited inundation occurs near the toll plaza as early as 24-inch scenario
  - Partial inundation of the westbound highway lanes first occurs at the 36-inch scenario with inundation depths of 0-3 feet

- Area C (Figure 2)
  - Partial inundation of the westbound highway lanes first occurs at the 36-inch scenario with inundation depths of 0-3 feet
  - Inundation underneath elevated highway segments

- Area D (Figure 3)
  - Access road and buildings are partially inundated first at the 36-inch scenario with inundation depths of 0-3 feet
  - Inundation underneath elevated highway segments

- Area E (Figure 3)
  - Burma Road is partially inundated first at the 36-inch scenario with inundation depths of 0-3 feet

- Area F (Figure 3)
  - Burma Road and some nearby buildings are partially inundated first at the 36-inch scenario with inundation depths of 0-3 feet

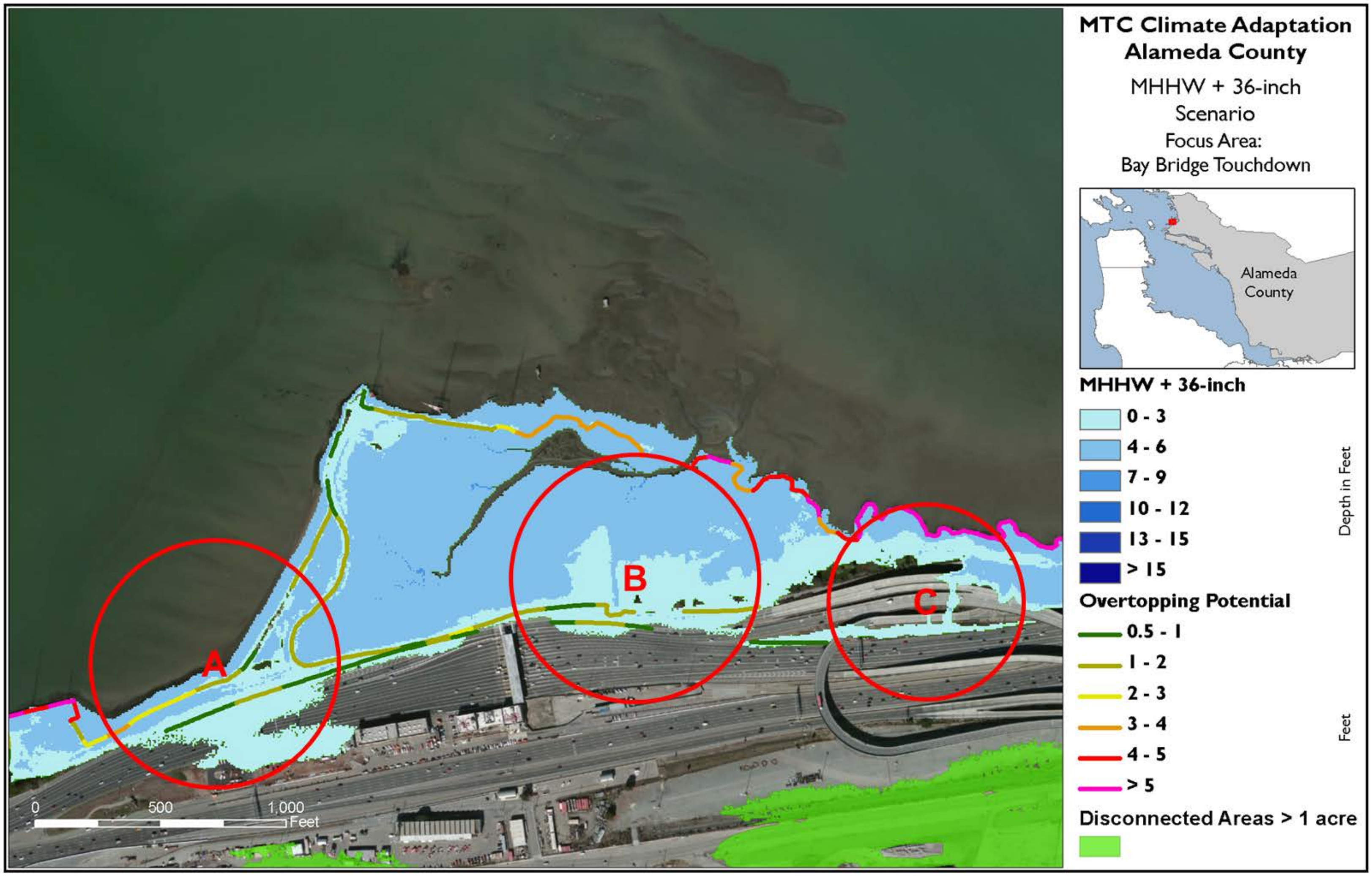

Figure 2. Shoreline Inundation Areas A, B, and C - MHHW + 36-inch Scenario

Figure 3. Shoreline Inundation Areas D, E, and F - MHHW + 36-inch Scenario

4.2 CRITICAL INUNDATION PATHWAYS

One critical inundation pathway was identified at the Bay Bridge Touchdown focus area (Area G in Figure 1). This low-lying hydraulic pathway allows floodwaters to penetrate landward from the shoreline to the inland inundation Areas H and I (Figure 4). Given the relatively large extent of inland inundation observed, AECOM sought to verify the mechanism of flooding and accuracy of the digital elevation model (DEM)[4] upon which the inundation maps were based to confirm the likelihood of flooding depicted. The DEM was compared to the original topographic Light Detection and Ranging (LiDAR) data points for this area to confirm that the modeled terrain surface of the DEM accurately represented the raw LiDAR data. Additionally, the orthoimagery from the 2010 LiDAR data collection and aerial photography from Google Earth (2014) were examined to confirm the location of the pathway and its surrounding features. Based on these examinations, the pathway appears to be formed by an engineered stormwater drainage area along Burma Road, which most likely drains to the Bay. Although intended for mitigating flooding due to precipitation and runoff, this stormwater drainage system is ineffective at preventing coastal floodwaters from propagating inland.

Figure 5 shows the elevation profile along the critical inundation pathway starting at the shoreline near Areas E and F and extending inland to Area H. The MHHW + 48-inch water level is shown for reference relative to the topography. As can be seen in Figure 5, the MHHW + 48-inch water level overtops both the shoreline protection infrastructure and the high point of the critical inundation pathway at an elevation of approximately 10 feet NAVD88. Once both of these features are overtopped, there is a continuous hydraulic connection from the shoreline to the inland inundation areas, which conveys floodwaters landward. Key observations for this critical inundation pathway are summarized below:

- Area G (Figure 4)
  - Inundation occurs at critical water level of approximately 10 feet NAVD88
  - Narrow drainage pathway along Burma Road at Port of Oakland Berth 8 connects the flooding from Areas E and F (Figure 3) to Areas H and I
  - Inundation first occurs at the 48-inch scenario with inundation depths of 0-3 feet

4.3 INLAND INUNDATION AREAS

Two key inland inundation areas were identified for the Bay Bridge Touchdown focus area. These areas are inundated via the critical inundation pathway (Area G) at the 48-inch scenario and are otherwise isolated from floodwaters for the lower sea level rise scenarios. Extensive inland flooding from multiple sources occurs at the 72-inch and 96-inch scenarios and extends northward towards the Emeryville Crescent. As stated in Section 3, these scenarios correspond with future extreme tide events and are unlikely to occur as permanent inundation before 2100. The inland inundation areas are summarized below:

[4] A 2-meter digital elevation model (DEM) was developed from the 2010 LiDAR data collected by the United States Geological Survey (USGS) and National Oceanic Atmospheric Administration (NOAA) as part of the California Coastal Mapping Program (CCMP)

- Area H (Figure 4)
  - Extensive inundation first occurs at the 48-inch scenario with depths of 0-6 feet
  - Mostly industrial land uses

- Area I (Figure 4)
  - Extensive inundation first occurs at the 48-inch scenario with depths of 0-6 feet
  - I-880, residential and commercial land uses

AECOM

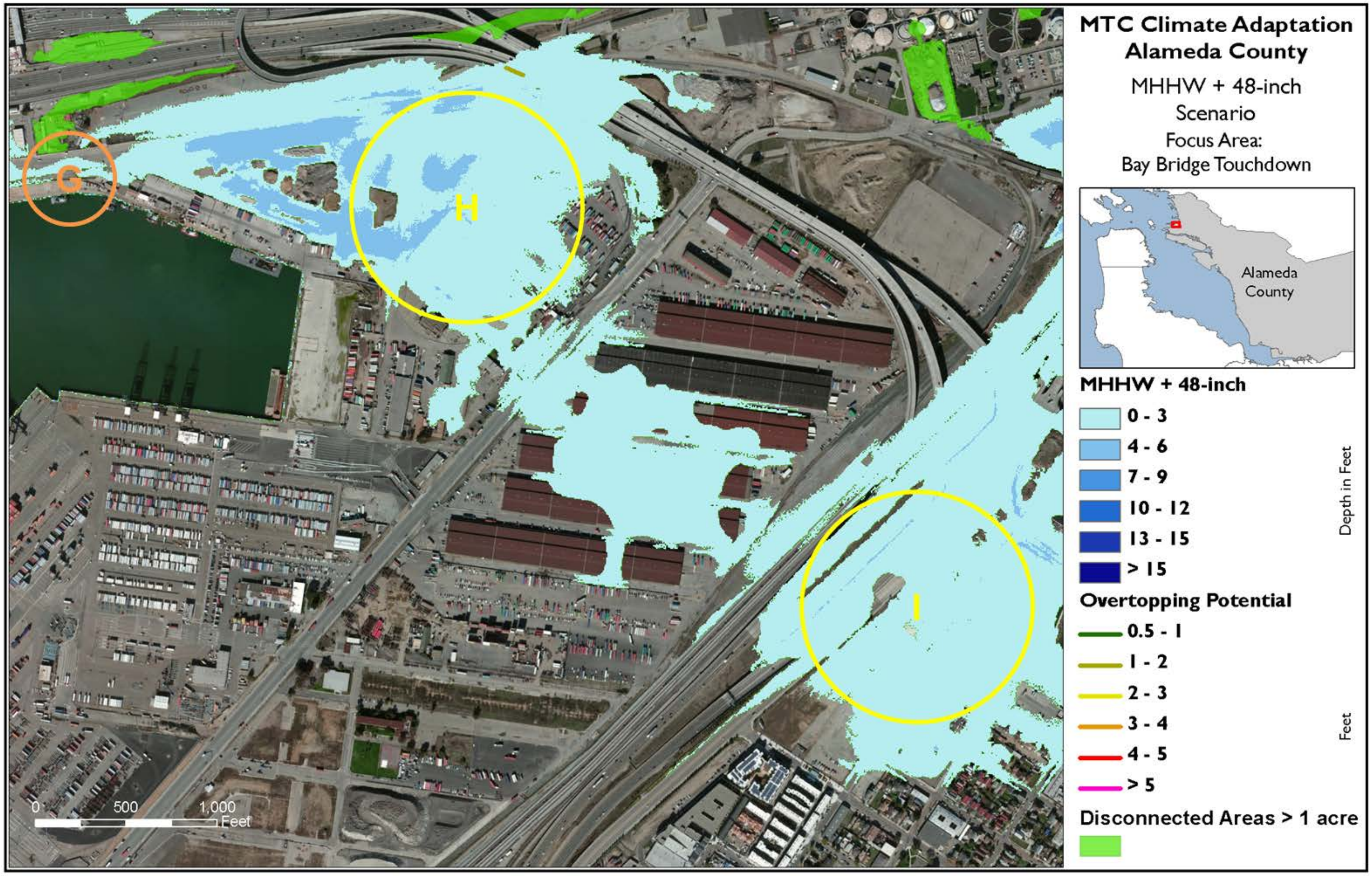

Figure 4. Critical Inundation Pathway (Area G) and Inland Inundation Areas (H-I) - MHHW + 48-inch Scenario

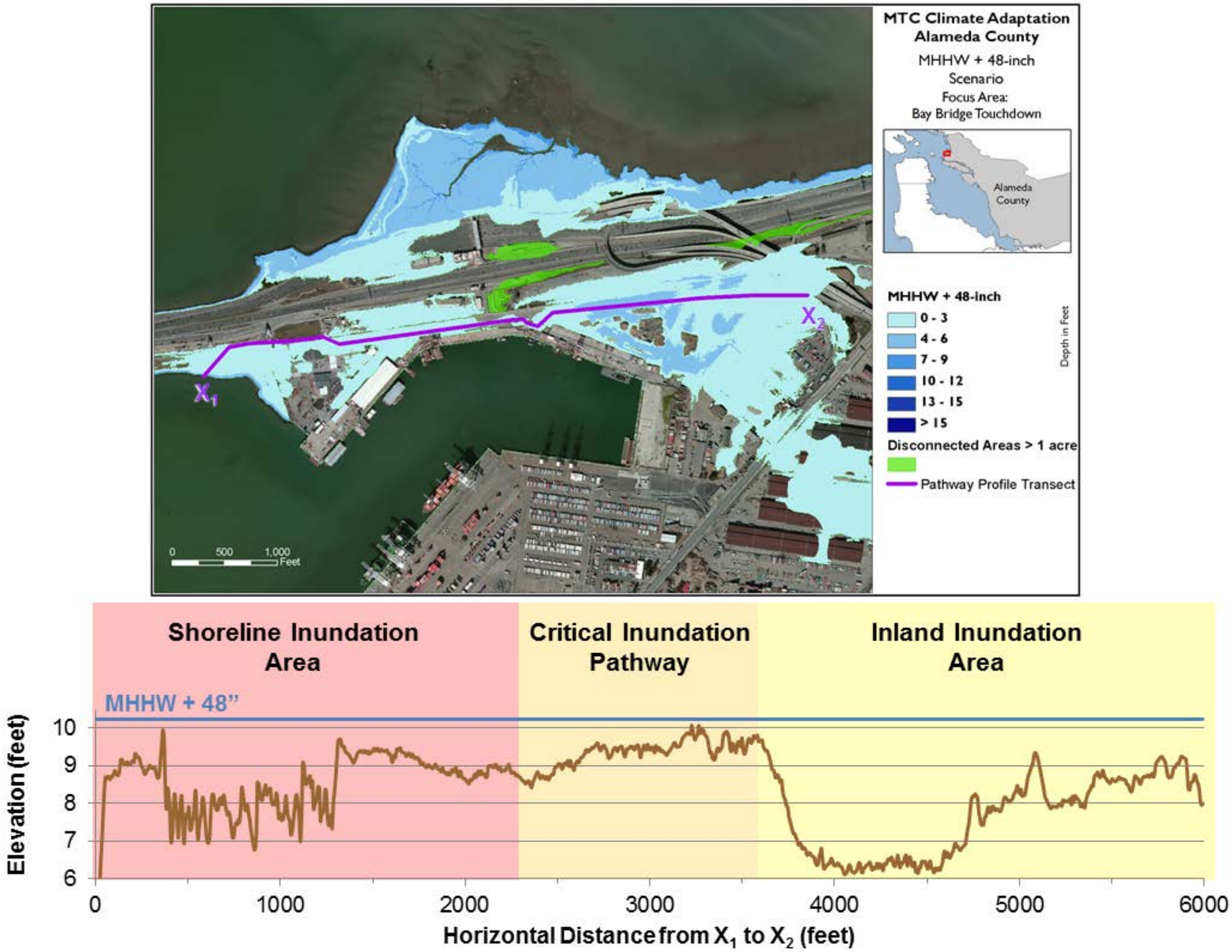

Figure 5. Plan and Profile View of Critical Inundation Pathway Connecting the Shoreline with Inland Inundation Areas

Notes: Profile outlined in purple in the plan view. Profile stationing reads from west (X_1) to east (X_2).

5. TIMING OF ADAPTATION MEASURES

The timing of adaptation measures is a key component of climate change adaptation planning. AECOM examined the timing of adaptation measures from the perspective of maintaining the existing level of flood protection in the face of rising sea level. The standard level of design for flood protection along the Bay shoreline is the 100-year (or 1-percent annual chance) flood[5], although in many areas this design criterion is not met. For the purposes of this study, the occurrence of various extreme tide levels under different sea level rise scenarios was evaluated. It should be noted that extreme tide levels presented in this memorandum do not include the effects of waves at the shoreline or the effects of precipitation based runoff and highway drainage and therefore may underestimate true flood risk. FEMA is currently in the process of updating Flood Insurance Rate Maps for this area which provide a more complete assessment of existing flood hazards.

Table 3 summarizes the timing of flooding for the shoreline inundation areas (A-F) and inland inundation areas (H-I) for various sea level rise scenarios. As discussed in Section 4, limited exposure to inundation occurs as early as the MHHW + 12-inch scenario along the northernmost highway lanes. The shoreline and inland inundation areas will be critically exposed to daily tidal inundation under the MHHW + 36-inch and MHHW + 48-inch sea level rise scenarios, respectively; however, these areas will be exposed to flooding by extreme tide events at much lower sea level rise scenarios. For example, core assets within the shoreline inundation area that will be exposed to daily tidal inundation under the MHHW + 36-inch sea level rise scenario could also be exposed to flooding once per year during 24 inches of sea level rise (24 inches of SLR + 1-year extreme tide), or repeatedly during El Niño[6] conditions with 6 inches of sea level rise (6 inches of SLR + 10-year extreme tide). The shoreline inundation areas (A-F) currently experience flooding under an existing 50-year extreme tide, while the inland inundation areas (H-I) require a coastal storm event greater than the 100-year level before they are flooded under existing conditions[7]. As sea levels increase over time, the level of flood protection for these areas will decrease and flooding will occur at a higher frequency. The reduction in level of flood protection due to sea level rise is shown in Table 3 for the shoreline and inland inundation areas. To maintain the existing level of flood protection along the shoreline areas, adaptation actions should be taken immediately. To maintain the existing level of flood protection (100-year) for the inland areas, adaptation actions should be considered before 6 inches of sea level rise occurs. Based on current guidance, 6 inches of sea level rise may occur by 2030 (NRC 2012). If no action is taken, sea level rise will continue to diminish the level of flood protection afforded by the existing shore protection infrastructure up until the point where the shoreline and inland areas are subject to daily tidal inundation.

[5] The 100-year flood is typically applied by the Federal Emergency Management Agency (FEMA) for developing Flood Insurance Rate Maps for coastal communities.

[6] The 10-year storm surge elevation is comparable to a typical El Niño winter condition in the Bay.

[7] It should be noted that localized areas of shoreline flooding may occur at less extreme tides and that the quoted levels of flood protection are based on a high-level examination of the inundation maps and do not represent a rigorous assessment of existing or future flood risk.

Table 3. Timing of Inundation and Flooding for Inundation Areas within the Bay Bridge Touchdown Focus Area

		Timing of Temporary Flooding from Extreme Tides (inches of SLR)						
Type	**Permanent Inundation Scenario (inches of SLR)**	**1-yr**	**2-yr**	**5-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**
Shoreline Inundation Areas (A-F)	+ 36	+ 24	+ 18	+ 12	+ 6	+ 6	Existing	Existing
Inland Inundation Areas (H-I)	+ 48	+ 36	+ 30	+ 24	+ 18	+ 18	+ 12	+ 6
System-wide	**+ 72**	**+ 60**	**+ 54**	**+ 48**	**+ 42**	**+ 42**	**+ 36**	**+ 30**

Note: Localized areas of shoreline flooding may occur at less extreme tides. The quoted levels of flood protection are based on a high-level examination of the inundation maps and do not represent a rigorous assessment of existing or future flood risk. “Existing” implies that a potential flooding scenario is possible under current conditions with no SLR.

In addition to the localized areas of inundation discussed in Section 4, the timing of system-wide inundation is also included in Table 3. System-wide inundation occurs when extensive inland areas are inundated by multiple sources, including the localized inundation areas and pathways identified for lower sea level rise scenarios. For example, along the northern shoreline, Areas A, B, and C result in daily tidal inundation of the highway at the 36-inch scenario. Although these areas are the earliest sources of inundation, the 72-inch and 96-inch scenarios reveal that almost the entire shoreline from Radio Beach to the Emeryville Crescent will ultimately be overtopped. For the timing of flooding indicated for the shoreline inundation areas (existing conditions), small-scale localized adaptation measures may be feasible. For the timing of flooding indicated for the system-wide flooding (30-36 inches), a large-scale integrated adaptation measure will be required.

6. PROPOSED ADAPTATION MEASURES

As a part of the overall MTC Climate Adaptation Pilot Project, several adaptation strategies have been outlined to address the existing and future flood vulnerabilities identified within the Bay Bridge touchdown focus area. Section 6.1 summarizes the proposed strategies for the northern portion of the focus area (Areas A-C) and Section 6.2 summarizes the proposed strategies for the southern portion of the focus area (Areas D-F).

6.1 NORTH OF BAY BRIDGE TOUCHDOWN (AREAS A – C)

To protect the vulnerable and low-lying areas on the north side of the touchdown, an engineered flood protection structure would likely be required. The flood protection structure could be more of a traditional levee structure, or it could be designed to be integrated within the existing wetland and beach habitats located on the north side of the touchdown. Suggested solutions include:

- Engineered berm with rock revetment: this structure would be located adjacent to the roadway along the entire length of the Bay Bridge touchdown. This structure could be a standalone structure that would provide sea level rise and storm protection to the roadway without providing any protection or linkages with the adjacent wetland habitats. Long-term maintenance would be required, and the structure may require the addition of periodic lifts to maintain the desired level of protection as sea levels rise. A feasibility assessment of roadway drainage collection, treatment, and discharge options would also be an important consideration in the development of this adaptation strategy.

- Engineered berm with habitat enhancements: this structure would provide protection from sea level rise and storm surge, but would be engineered to maintain the link with adjacent wetland habitats by maximizing the use of natural and living (vegetative) materials. Exposure to erosion and other natural processes in the Bay would require this strategy to include active long-term management (e.g., nourishment) and possibly restoration efforts to ensure adjacent habitats keep pace with sea level rise. A feasibility assessment of roadway drainage collection, treatment, and discharge options would also be an important consideration in the development of this adaptation strategy.

- Artificial dunes: constructing artificial dunes along the entire length of the low-lying section north of the Bay Bridge Touchdown is an adaptation strategy that retains habitat value in the area while protecting highway assets. The longer-term resiliency of this strategy may require the addition of an offshore breakwater to reduce erosion from wave action.

- Offshore breakwater: this structure has been proposed as a possible adaptation strategy that can be used in tandem with any of the suggested berm or dune strategies along the roadway. Although construction of such a structure would not mitigate sea level rise, it would serve to reduce damaging storm surge and wave effects, thereby prolonging the useful life of the berm or dune strategies, while also protecting valuable habitats north of the bridge.

6.2 SOUTH OF BAY BRIDGE TOUCHDOWN (AREAS D – F)

The vulnerabilities to flooding along the south side of the Bay Bridge touchdown are more complex, and the suggested adaptation strategies will provide protection to the Bay Bridge and adjacent assets within the focus area. Potential adaptation strategies include:

- Construction of a low berm or sea wall to separate the proposed Gateway Park site from the Port of Oakland assets to the east. This strategy would address the critical inundation pathway along Burma Road (Area G). This strategy would not provide protection for assets to the west and north, but it would prevent inland inundation to the east.

- Raising Burma Road. This strategy could mitigate the critical inundation pathway while also providing emergency access to the Bay Bridge touchdown area. Assets to the west would likely remain vulnerable to exposure while assets to the east and north would be protected from flooding and inundation by his strategy.

- Natural and/or engineered shoreline protection will be an essential part of the proposed construction of Gateway Park. The shoreline could include features at or near the existing grade with landscape elements that incorporate high marsh and riparian habitat features that readily accommodate flooding by extreme tides and storm surge. Terracing of the landscape and raising existing structures are also proposed as possible strategies to increase the resilience and protection provided by the proposed park.

7. CONCLUSIONS AND NEXT STEPS

Nine key inundation vulnerability areas were identified within the Bay Bridge Touchdown focus area (Figure 1). Six of these are shoreline inundation areas, one is a critical inundation pathway, and two are inland inundation areas. The threshold for critical localized daily tidal inundation along the shoreline (Areas A-F) occurs at the MHHW + 36-inch scenario; however, extreme tides (50-year or greater) already threaten assets immediately adjacent to the shoreline under existing conditions. The threshold for daily tidal inundation of inland areas (Areas G-I) occurs at the MHHW + 48-inch scenario; however, extreme tides (50-year or greater) will threaten these areas in the future with just 6 to 12 inches of sea level rise. In the short term (0-6 inches), small-scale localized shoreline adaptation measures may protect critical assets from flooding during extreme tides; however, over the long term (approximately 36 inches of sea level rise and greater), a large-scale integrated flood protection strategy for the Bay Bridge Touchdown focus area will be required to prevent extensive flooding during extreme tides. Any responsible adaptation measure should consider the combined impact of coastal storm surge, waves, and roadway drainage and runoff. The cumulative impacts of rainfall runoff storm events occurring during periods of extreme tide levels were not considered in this analysis; however, these events will further exacerbate flooding within this focus area. In addition, rising groundwater tables, primarily associated with static sea level rise, can impact flooding and drainage by reducing infiltration and sub-surface storage of runoff. The existing highway drainage systems will become less effective over time and they may become completely ineffective with higher levels of sea level rise. These additional considerations are outside the scope of our current study, but evaluation of these factors is recommended as a next step.

8. REFERENCES

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Attachment A – Bay Bridge Focus Area Site Visit Photos

AECOM

Attachment A - Site Visit Photos (March 7, 2014)

Bay Bridge Touchdown Focus Area – Radio Beach (Area A)

Bay Bridge Touchdown Focus Area – Radio Beach (Area A)

Bay Bridge Touchdown Focus Area – Western Tip of Burma Road (Area D)

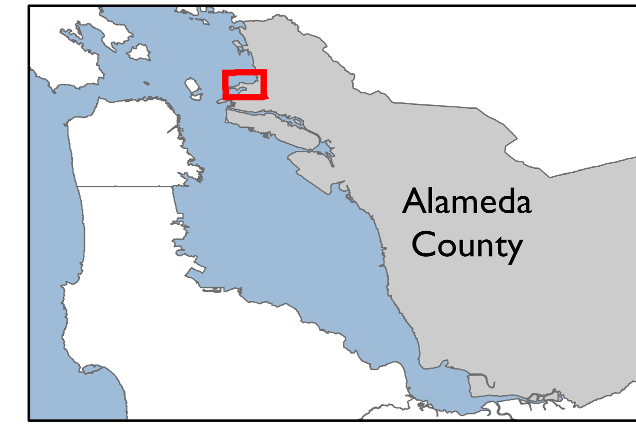
Bay Bridge Touchdown Focus Area – Southern Shoreline along Burma Road (Area E)

Attachment B – Focus Area Inundation Maps

MTC Climate Adaptation Alameda County

MHHW + 12-inch Scenario

Focus Area: Bay Bridge Touchdown



MHHW + 12-inch

Depth in Feet

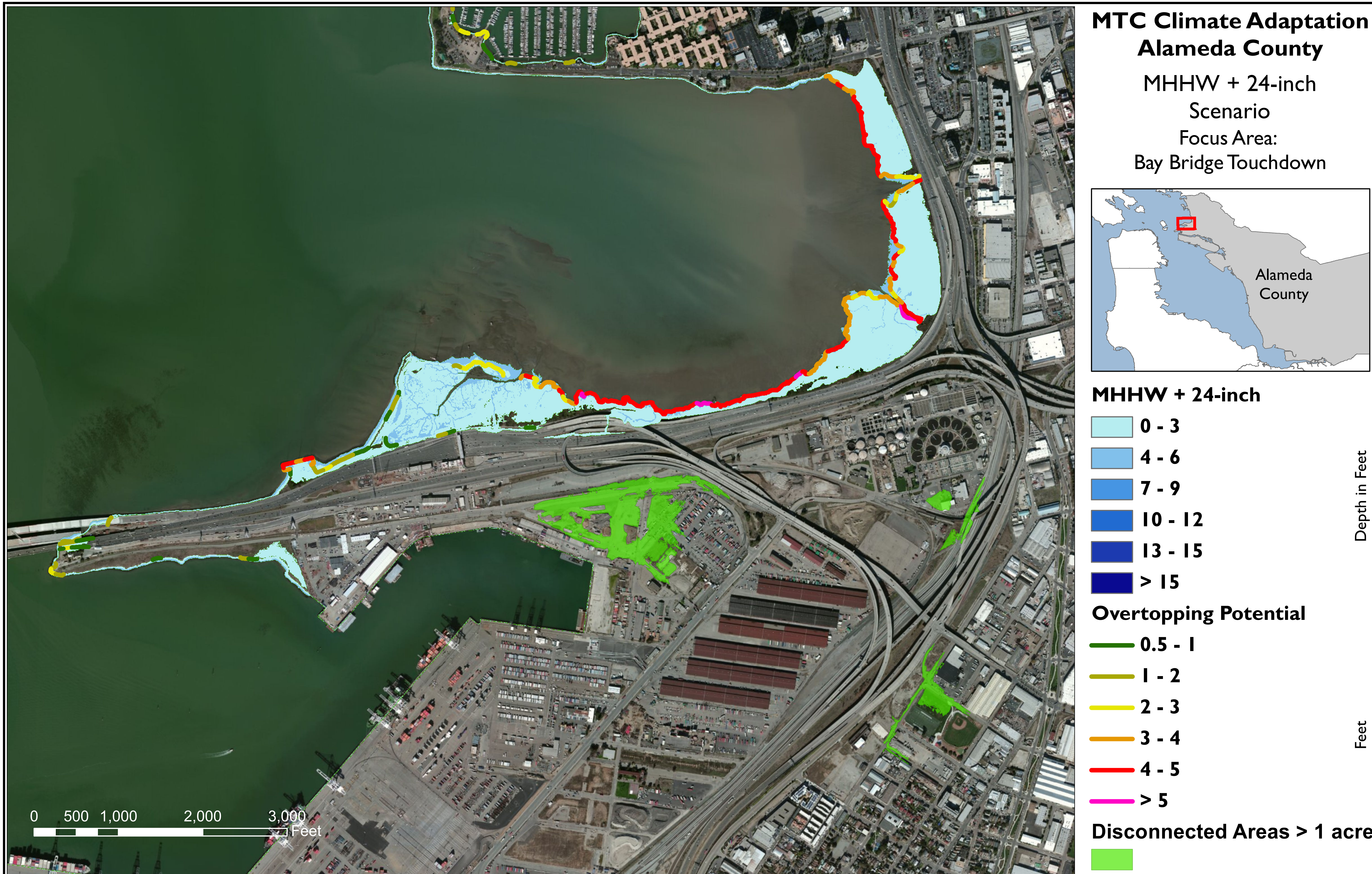
- 0 - 3
- 4 - 6
- 7 - 9
- 10 - 12
- 13 - 15
- > 15

Overtopping Potential

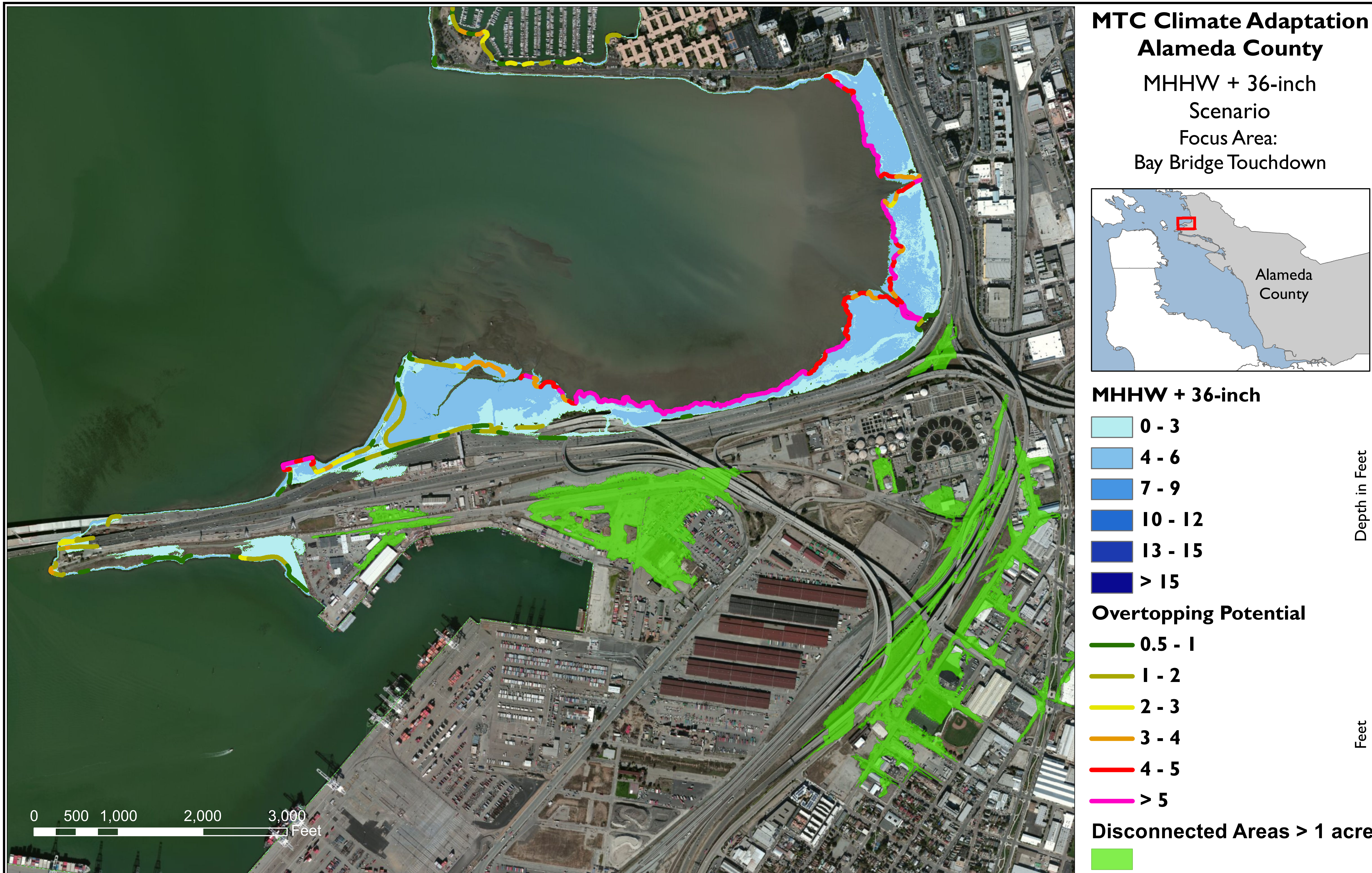
Feet

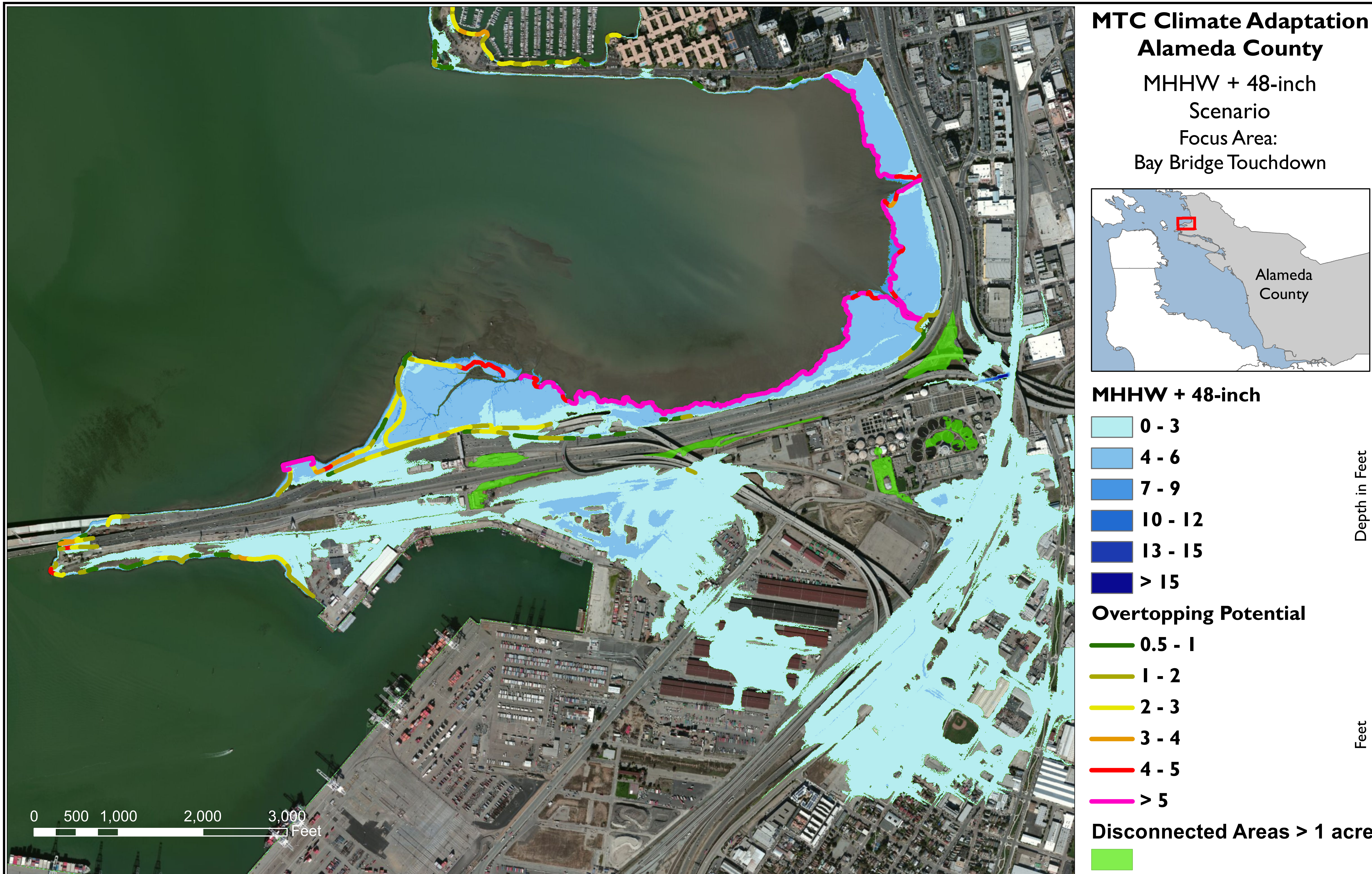
- 0.5 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- > 5

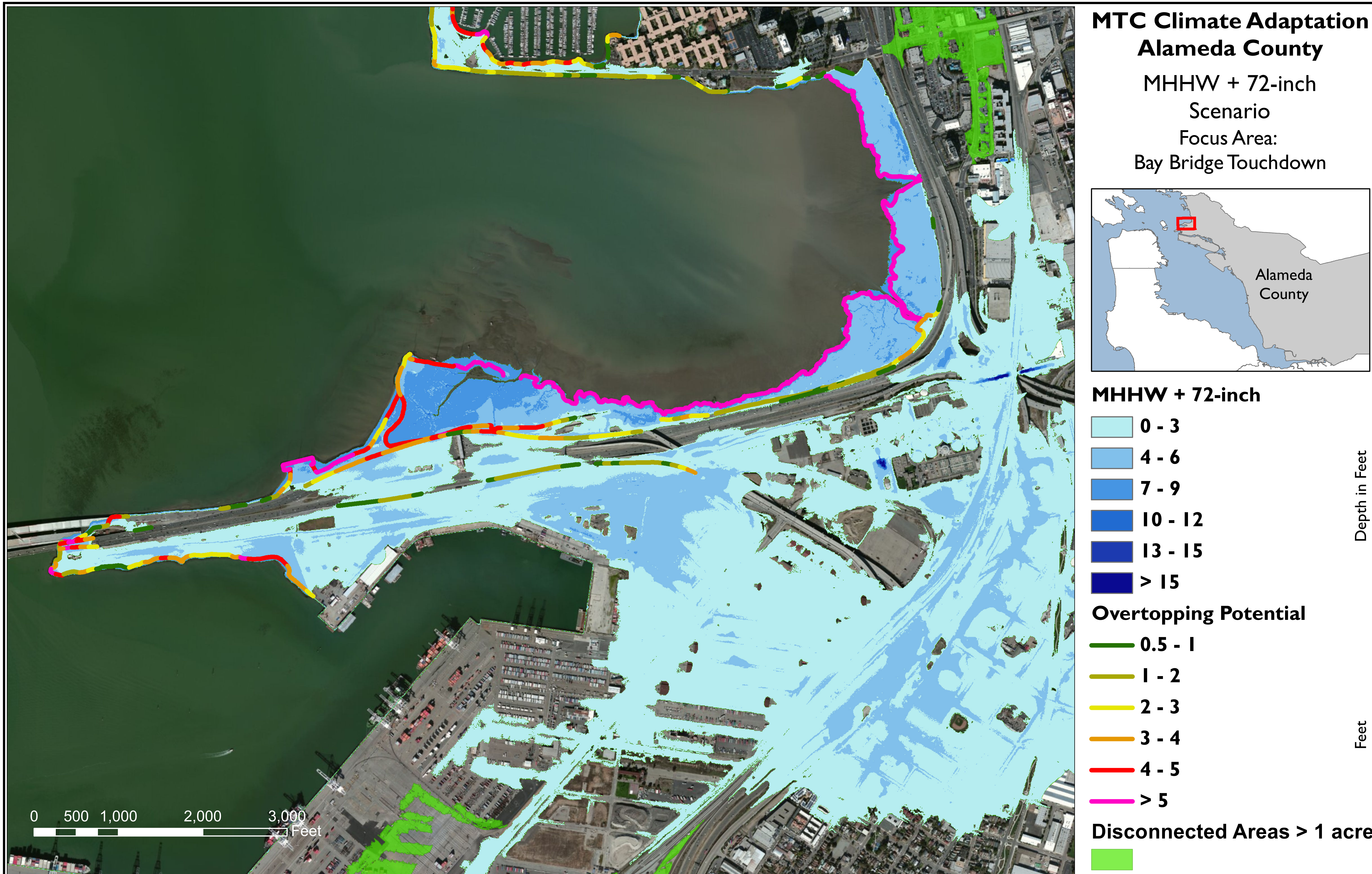
Disconnected Areas > 1 acre



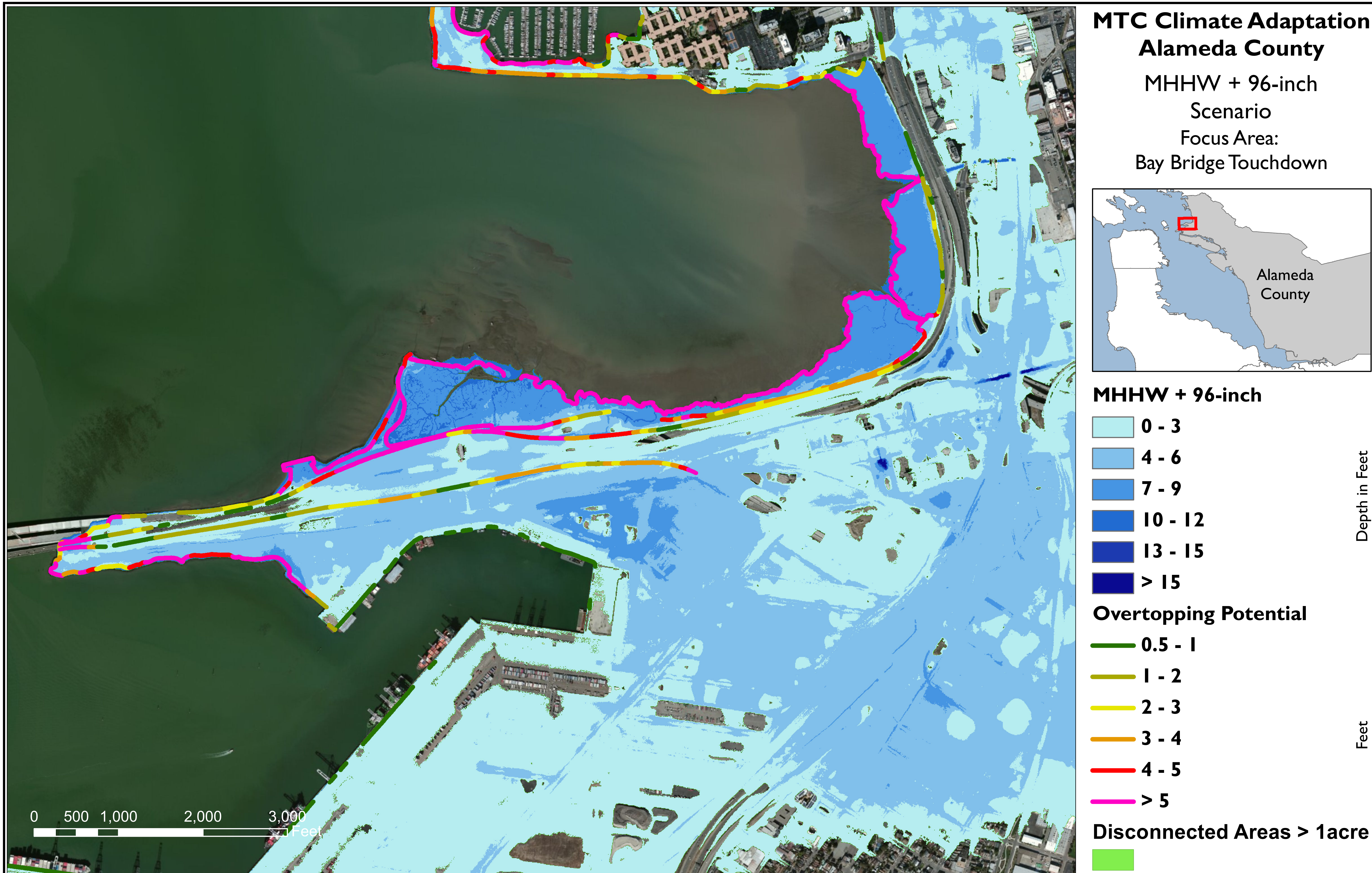
MTC Climate Adaptation
Alameda County
MHHW + 24-inch
Scenario
Focus Area:
Bay Bridge Touchdown
Alameda County
MHHW + 24-inch
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Depth in Feet
Overtopping Potential
0.5 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Feet
Disconnected Areas > 1 acre
0
500
1,000
2,000
3,000
Feet


MTC Climate Adaptation
Alameda County
MHHW + 36-inch
Scenario
Focus Area:
Bay Bridge Touchdown
Alameda
County
MHHW + 36-inch
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Depth in Feet
Overtopping Potential
0.5 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Feet
Disconnected Areas > 1 acre
0 500 1,000 2,000 3,000
Feet


MTC Climate Adaptation
Alameda County
MHHW + 48-inch
Scenario
Focus Area:
Bay Bridge Touchdown
Alameda
County
MHHW + 48-inch
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Depth in Feet
Overtopping Potential
0.5 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Feet
Disconnected Areas > 1 acre
0 500 1,000 2,000 3,000
Feet



MTC Climate Adaptation
Alameda County
MHHW + 72-inch
Scenario
Focus Area:
Bay Bridge Touchdown
Alameda
County
MHHW + 72-inch
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Depth in Feet
Overtopping Potential
0.5 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Feet
Disconnected Areas > 1 acre
0
500
1,000
2,000
3,000
Feet


MTC Climate Adaptation
Alameda County
MHHW + 96-inch
Scenario
Focus Area:
Bay Bridge Touchdown
Alameda
County
MHHW + 96-inch
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Depth in Feet
Overtopping Potential
0.5 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Feet
Disconnected Areas > 1acre
0
500
1,000
2,000
3,000
Feet

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Memorandum

To	Stefanie Hom (MTC)	Page 1
CC	Wendy Goodfriend (BCDC), Dick Fahey (Caltrans), Norman Wong (BART), Clair Bonham-Carter (AECOM)	
Subject	Oakland Coliseum – Damon Slough/Arroyo Viejo Creek	
From	Michael Mak, PE; Kris May, PhD PE; and Vince Geronimo, PE	
Date	July 29, 2014	

1. INTRODUCTION

The Oakland Coliseum area was selected as a focus area for more detailed exposure analysis and adaptation strategy development as part of the current Metropolitan Transportation Commission (MTC) Climate Adaptation Pilot Study. Under the precursor MTC Vulnerability and Risk Assessment Project[1], this area was vulnerable to inundation by sea level rise and coastal storm surge that could impact core transportation assets that support the region: Interstate-880 (I-880), the Coliseum Amtrak Station, the Coliseum/Oakland Airport BART Station, and the new Oakland Airport BART Connector Station. The current Pilot Study includes a more detailed analysis of potential inundation by sea level rise and storm surge, and the parking lots adjacent to the Oakland Coliseum are inundated with 36 inches of sea level rise[2] (or a storm surge scenario that results in a similar level of inundation), and nearly the entire focus area is inundated with 48 inches of sea level rise. However, these results do not consider the additional impact of riverine-induced flooding due to precipitation events. As shown in Figure 1, Damon Slough and its tributaries, Arroyo Viejo Creek and Lion Creek, are located directly adjacent to the core transportation assets. The purpose of this technical memorandum is to explore the potential inundation that could occur due to the combination of sea level rise and riverine flooding, and to identify when and where adaptation strategies may be needed to protect both the core transportation assets, as well as other adjacent assets identified by the project management team (PMT).

This technical memorandum should be considered in tandem with other ongoing work by the San Francisco Bay Conservation and Development Commission (BCDC) and Alameda County Flood Control and Water Conservation District (ACFCWCD) to better understand sea level rise, storm surge, and

[1] Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, November 2011.

[2] The sea level rise scenario when overtopping first occurs in the focus area has been approximated based on the mapped sea level rise inundation scenarios (e.g., 12", 24", 36", 48") for the current Pilot Study. The actual sea level rise scenario which results in overtopping of shoreline features may be less than this amount (i.e., if the SLR scenario of first overtopping is 36 inches, overtopping is first observed in this mapped scenario, but overtopping may occur as early as 25 inches). Refined shoreline tools have been developed for this area that can estimate the overtopping threshold within 6 inch increments, and these tools can be used for future updates to this assessment.

shoreline vulnerabilities in Alameda County. The following sections provide a description of the Oakland Coliseum focus area, an overview of the analysis approach, and a discussion of the results.

2. FOCUS AREA DESCRIPTION

The Oakland Coliseum focus area is located inland of the Martin Luther King, Jr. Regional Shoreline of San Leandro Bay in Alameda County, California (see Figure 1). The shoreline is characterized by intermittent salt marshes and mudflats, rip-rap, and vegetated banks. Damon Slough drains directly into San Leandro Bay, and is fed by its upstream tributaries Arroyo Viejo Creek and Lion Creek. The tributaries drain portions of the vast Oakland hills through a complex storm drain system comprised of engineered channels and hydraulic conveyance structures. Arroyo Viejo Creek daylights just upstream of the Amtrak rail crossing and Lion Creek daylights north of Lucille Street near Greenman Field. Damon Slough, Arroyo Viejo Creek, and Lion Creek are all channelized and surrounded with highly urbanized and paved areas. Figure 2 shows a delineation map of the surrounding watersheds and the contributing watersheds to the focus area.

During rainfall-driven storm events, the channels convey stormwater and urban runoff from the contributing watersheds to San Leandro Bay. The flows in Damon Slough must pass through a series of channel constrictions associated with the Oakport Street, I-880, Coliseum Industrial, and Coliseum Way overpasses. Each channel constriction can result in backed-up flows and overbank flooding if flows are high enough. Under existing conditions (i.e., in the absence of sea level rise), flooding occurs at discrete areas along Damon Slough during a 100-year rainfall event coupled with a 10-year storm surge event (e.g., a downstream Bay water level consistent with moderate El Niño conditions). As sea levels rise, smaller rainfall events combined with lower downstream Bay water levels may result in similar and/or more severe flooding and inundation.

The primary core assets and key vulnerabilities defined for this focus area include:

- I-880/Damon Slough Bridge
    - Potential scour at abutments from increasing wind, wave, or tidal energy
    - Potential increase in channel erosion
    - Overtopping of roadway
- Oakland Coliseum Complex
    - Vulnerable infrastructure at existing ground elevations
    - Disruptions in service during periods of flooding
- Oakland Coliseum Amtrak Station
    - Vulnerable utilities below existing ground elevations
    - Disruptions in Amtrak service if service corridor (rail track) is exposed to flooding
    - No alternative rail transit if service is disrupted
- Oakland Coliseum BART Station
    - Elevated transit facility, but no alternative station if service is disrupted
    - Vulnerable access points at and below existing ground elevations
    - Vulnerable facilities at existing ground elevations
    - Disruption in alternative AC Transit service from localized flooding of roadways
- Oakland Airport Connector
    - Elevated transit facility, but no alternative station if service is disrupted
    - Vulnerable power stations and utilities located at existing ground elevations
    - Disruption of access if Coliseum or surrounding access points are flooded

AECOM

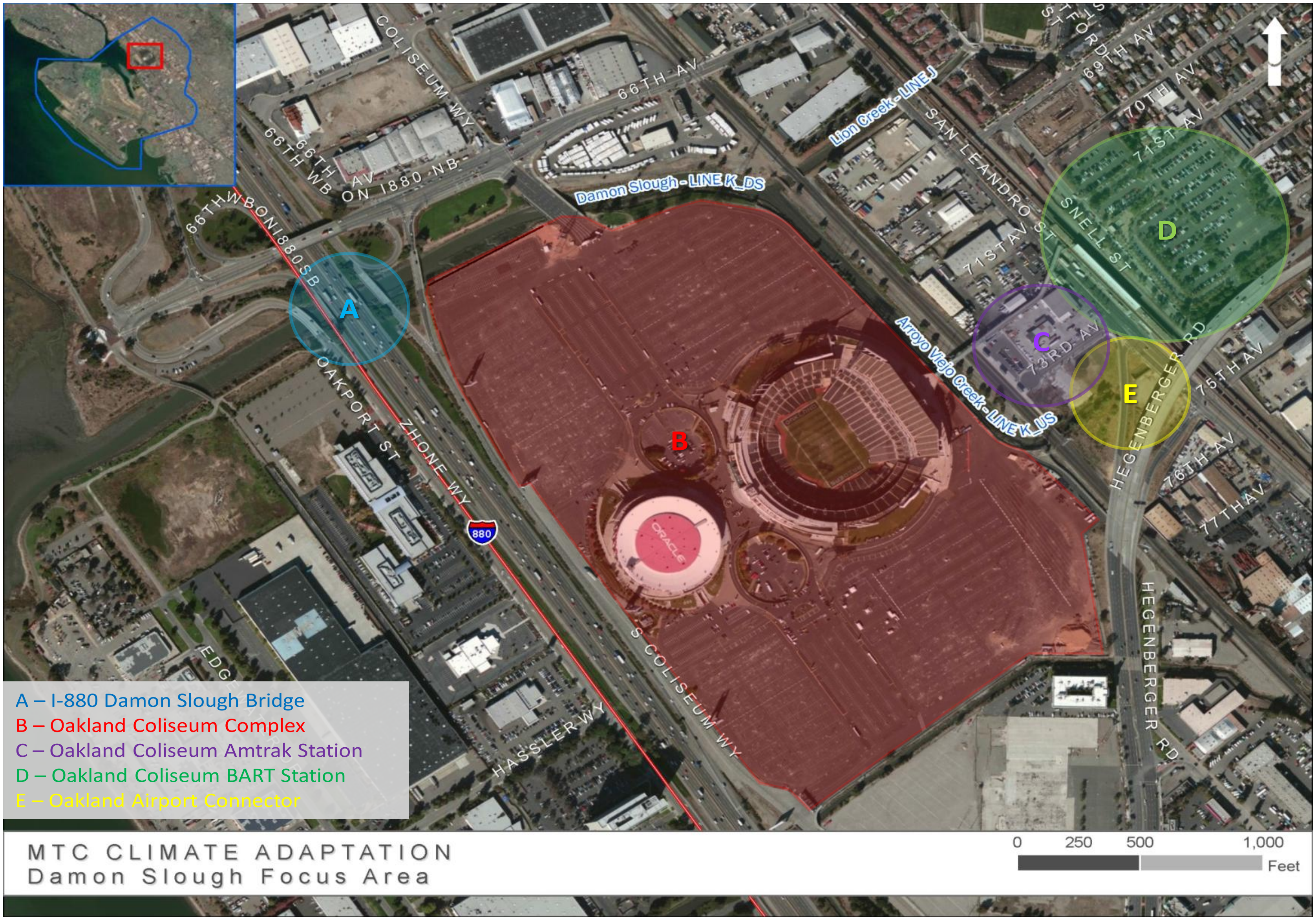

Figure 1 – Overview of Oakland Coliseum Focus Area

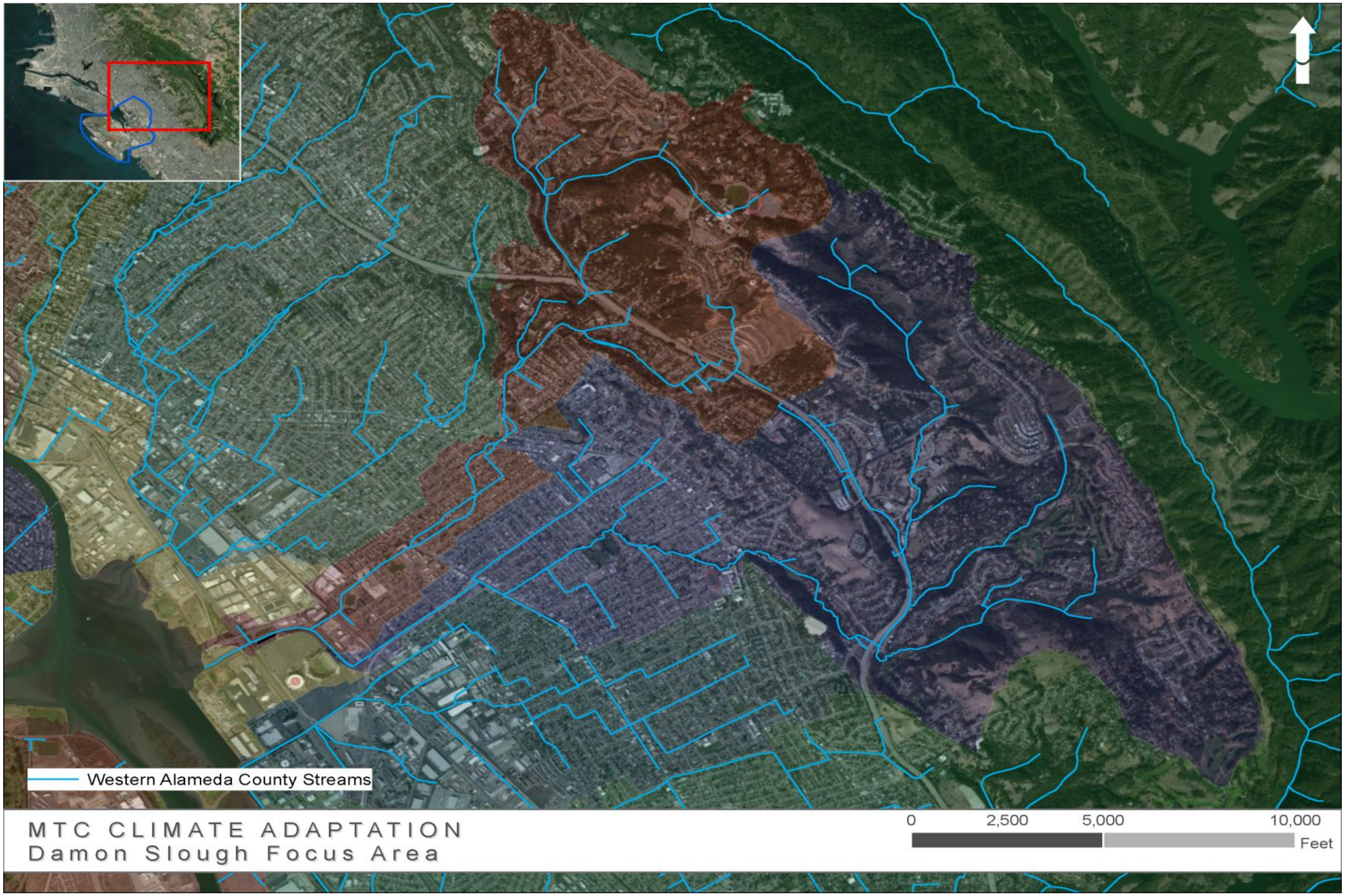

Figure 2 – Watershed Map for Oakland Coliseum Focus Area[3]

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[3] Source: Sowers, J.M., Richard, C., Dulberg, R. and Holmberg, J.F., 2010, Creek & watershed map of the Western Alameda County: a digital database, version 1.0: Fugro William Lettis and Associates, Inc., Walnut Creek, CA, 1:24,000 scale.

3. ANALYSIS APPROACH

Assessing the combined impact of riverine flooding, sea level rise, and coastal storm surge scenarios requires the use of a numerical model that has been developed and calibrated for the specific system of interest. AECOM leveraged an existing steady-state HEC-RAS hydraulic and hydrologic model of Damon Slough, Arroyo Viejo Creek, and Lion Creek from ACFCWCD. The HEC-RAS model was used to evaluate various combinations of downstream Bay water levels, sea level rise, and peak flow events in the slough and creek channels to help understand the key thresholds that can result in overbank flow and inundation within the Oakland Coliseum focus area.

The following sections describe the leveraged HEC-RAS model, the modeled scenarios, and the boundary conditions applied within the model.

3.1. Steady State HEC-RAS Model

An existing steady-state HEC-RAS model of Damon Slough and its tributaries can be used to calculate extreme event water levels along the modeled reaches of the slough and creeks by adjusting the downstream tidal boundary and/or the upstream peak discharge boundary. The HEC-RAS model leveraged for this analysis was initially developed by the ACFCWCD in 2003, and subsequently modified by Philip Williams and Associates (PWA) in 2005, to include additional surveyed cross section data and other model refinements. The steady-state model does not consider the timing of peak flows in the channels generated from different watershed characteristics. Peak flows occurring in the channels at different times can lead to lower flood levels.

Although the HEC-RAS model provides adequate hydraulic and hydrologic data (e.g., channel cross section data, discharge boundary information, overbank mannings n values) for a high-level assessment of potential flooding, it should be noted that this model has not been updated since 2005 to account for channel modifications or changes in land use that may have occurred after 2005.

It should be noted that several existing bridge and culvert structures are not included in the HEC-RAS model, most notably, the Coliseum Way, Oakport Street and I-880 overpasses. This could result in an under-estimation of the potential for flooding in these reaches. In addition, a recent channel diversion at Lion Creek that was designed to attenuate peak flows through a restored area upstream of the confluence with Arroyo Viejo Creek is not included in the HEC-RAS model. This absence of this modification in the model could result in an overestimation of potential flooding in this reach.

AECOM leveraged the model as is and made minor modifications to support the analysis[4], but significant effort was not invested to add additional cross sections or to account for any potential updates needed to more accurately represent the current system. ACFCWCD is currently in the process of updating their hydrologic and hydraulic models in this area (Oakland, ACFCWCD Zone 12), and updated models are expected to be available within a two-year timeframe.

3.2. Scenarios

In the discussion that follows, flooding occurs from two distinct processes. The first is riverine flooding –extreme rainfall runoff driven peak flow events in the stream network during periods of average high tide conditions in the Bay. The second is combined riverine and storm surge flooding –smaller peak flows in the stream network that coincide with periods of episodic, short duration, extreme tide events of greater magnitude than normal tide levels. Inland areas may be temporarily flooded during a

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[4] The leveraged HEC-RAS model was not geo-referenced to an existing horizontal datum. AECOM manipulated the existing model so that the model output could be geo-referenced for inundation mapping purposes.

riverine flood or combined riverine and storm surge event while maintaining at least a portion of their functionality once the floodwaters recede. However, sensitive assets may suffer irreversible damage if exposed to any amount of water, even temporarily. Assets may only be exposed to freshwater from riverine flooding, but can be exposed to saline water during flooding from riverine and storm surge events. The term flooding, as it is used throughout this memorandum, is a temporary inundation condition that results from a storm event rather than the permanent inundation due to daily high tides. Permanent inundation can come with regular tidal inundation, which was not examined in this analysis.

The HEC-RAS model was used to evaluate various combinations of downstream Bay water levels (i.e., MHHW, 10-year storm surge, and 100-year storm surge), sea level rise (i.e., 12 inches and 24 inches), and peak flow events in the slough and creek channels (i.e., 10-year flow and 100-year flow). Although numerous potential combinations of Bay water levels, sea level rise, and peak flow events can be used to evaluate the system, the selected combination of events were designed to help understand the key thresholds that can result in overbank flow and inundation within the Oakland Coliseum focus area.

Average daily tide conditions can be represented by applying the MHHW level at the downstream boundary. The 10-year storm surge elevation is comparable to a typical El Niño winter condition, and the 100-year storm surge elevation is the coastal flood hazard level used by FEMA for developing Flood Insurance Rate Maps for coastal communities. In the absence of riverine flooding, the critical threshold for inundation occurs with 36 inches of sea level rise. However, when riverine flooding is also considered, the threshold is likely lower; therefore two lower sea level rise scenarios were evaluated in combination with the riverine flooding: 12 and 24 inches.

The 10- and 100-year peak flow rates for the Damon Slough, Arroyo Viejo, and Lion Creek reaches are paired with the various downstream tidal boundary conditions. The 10-year peak flow rate can be associated with a precipitation event that occurs during an El Niño winter, and similarly with the coastal storm surge elevations, the 100-year peak flow rate is typically used by FEMA for calculating base flood elevations as shown on the FIRMs for communities adjacent to rivers and creeks.

A summary of the simulations evaluated using the HEC-RAS model is presented in Table 1. The 100-year coastal storm surge elevation was not evaluated in combination with the 100-year riverine peak flow event. This combination would represent an event with a recurrence interval much greater than a 100-year event. The goal of this analysis was to determine the thresholds when inundation begins, and not necessarily to evaluate extreme inundation scenarios.

Table 1: Selected Analysis Scenarios

Tide Condition	Peak Flow	Description
MHHW	**10-year**	10-year peak flow rate during higher high tide conditions.
+ 12" SLR	10-year	10-year peak flow rate during higher high tide conditions with 12" SLR.
+ 24" SLR	10-year	10-year peak flow rate during higher high tide conditions with 24" SLR.
MHHW	**100-year**	100-year peak flow rate during higher high tide conditions. 100-year peak discharge typical for FEMA studies.
+ 12" SLR	100-year	100-year peak flow rate during higher high tide conditions with 12" SLR.
+ 24" SLR	100-year	100-year peak flow rate during higher high tide conditions with 24" SLR.
10-year	**10-year**	10-year peak flow rate during 10-year storm surge levels. Similar to typical event experienced during El Niño winter.
+ 12" SLR	10-year	10-year peak flow rate during 10-year storm surge conditions with 12" SLR.
+ 24" SLR	10-year	10-year peak flow rate during 10-year storm surge conditions with 24" SLR.
10-year	**100-year**	100-year peak flow rate during 10-year storm surge conditions.
+ 12" SLR	100-**year**	100-year peak flow rate during 10-year storm surge conditions with 12" SLR.
+ 24" SLR	100-**year**	100-year peak flow rate during 10-year storm surge conditions with 24" SLR.
100-year	**10-year**	10-yr peak flow rate during 100-year storm surge conditions. 100-year storm surge typical for FEMA studies.
+ 12" SLR	10-**year**	10-year peak flow rate during 100-year storm surge conditions with 12" SLR.
+ 24" SLR	10-**year**	10-year peak flow rate during 100-year storm surge conditions with 24" SLR.

3.3. Boundary Conditions

3.3.1. Upstream Riverine Boundary

The upstream boundary conditions listed within the documentation supplied with the existing HEC-RAS model for Arroyo Viejo Creek and Lion Creek were used this analysis. These peak flow rates were used by PWA in previous modeling efforts, and were taken from the FEMA Flood Insurance Study (FIS) for the City of Oakland (FEMA 1982). On the FEMA Flood Insurance Rate Map (FIRM) for Alameda County, Damon Slough is referred to as Line K_DS, Arroyo Viejo Creek is referred to as Line K_US, and Lion Creek is referred to as Line J (FEMA 2009). Table 2 presents the peak flow rates used for the upstream reach boundary conditions in this study.

Table 2: Reach Boundary Conditions – Peak Flow Rates (10-Year and 100-year)

Reach	FEMA FIS Reach	Peak Flow	
		10-Year	100-Year
Damon Slough	Line K_DS	2,600 cfs	4,000 cfs
Arroyo Viejo Creek	Line K_US	1,600 cfs	2,800 cfs
Lion Creek	Line J	1,200 cfs	1,900 cfs

3.3.2. Downstream Tidal Boundary

The downstream tidal boundary conditions used in this study include MHHW and the10-year and 100-year storm surge (a.k.a. extreme tide) elevations. These elevations were derived from MIKE21 model output from a regional San Francisco Bay modeling study completed as part of the FEMA San Francisco Bay Area Coastal Study [5](DHI 2011). The modeling study spanned a 31-year hindcast period from January 1, 1973 to December 31, 2003 (31 years). The water level data was extracted at a location near San Leandro Bay, and the entire 31-year simulation period was analyzed to determine the 10-year and 100-year storm surge elevations using statistical analysis. The MHHW tidal datum was calculated using the portion of the model output time series corresponding to the most recent National Tidal Datum Epoch (1983 through 2001), which is a specific 19-year period adopted by the National Oceanic and Atmospheric Administration (NOAA) to compute tidal datums. Table 3 presents the daily and extreme tide levels used for Damon Slough tidal boundary conditions.

Table 3: Tidal Boundary Conditions

Reach	FEMA FIS Reach	Elevation (FT-NAVD88)		
		MHHW	10-Year	100-Year
Damon Slough	Line K_DS	6.61	8.84	10.01

[5] www.r9coastal.org

4. FLOOD EXTENT MAPPING

The inundation mapping for this focus area relied on two primary data sources:

- 2-meter digital elevation model (DEM) developed from the 2010 Light Detection and Ranging (LiDAR) data collected by the USGS and NOAA as part of the California Coastal Mapping Program (CCMP)
- HEC-RAS model output water surface elevations at each channel cross section

After spatially adjusting the existing HEC-RAS model to the correct horizontal datum, the flood extent mapping for the Oakland Coliseum focus area was completed using AECOM's proprietary Hydraulic Analyst toolbox for Esri's ArcMap software. The Hydraulic Analyst tool was created for mapping water surface elevations for riverine studies, including the creation of FEMA FIRMs. The Hydraulic Analyst toolbox assists the user in mapping backwater conditions, employing a modified bathtub approach similar to the NOAA Coastal Services Center approach for mapping sea level rise inundation. In this study, potential low-lying disconnected areas were not removed in order to be conservative, as these areas may be flooded if a hydraulic connection (i.e., culverts, storm drains, or other hydraulic features) exists between the low-lying area and the flooding source.

It is important to note that the DEM used for the inundation mapping is associated with 2010 topographic conditions, and the HEC-RAS model is associated with 2005 conditions surveyed at specific cross sections. There are likely differences and discrepancies between the DEM and the HEC-RAS cross sections in areas where significant changes have occurred over time. These differences, and their potential impact on the modeled results, were not fully investigated as part of this modeling effort due in part to the limited level of documentation that accompanied the leveraged HEC-RAS model.

Although fifteen combinations of Bay water levels, sea level rise, and riverine peak flows were analyzed, as shown in Table 1, only eight scenarios were mapped for illustrative purposes, as presented in Table 4. There were limited differences observed on the maps between 12- and 24-inches of sea level rise, therefore only the existing conditions and 24 inches of sea level rise scenarios were mapped to compare the differences in flooding extent. It should be emphasized that flooding can occur under existing conditions, and flooding is expected to worsen with 12 inches of sea level rise. The identification, development and implementation of adaption strategies is required in the near term to protect existing assets. With 12 inches of sea level rise, smaller peak riverine flow events can result in flooding than currently observed under existing conditions. With 24 inches of sea level rise, extensive flooding can occur throughout the focus area. Both the 12 inch and 24 inch sea level rise scenarios should be considered in the adaptation strategy planning process -- the flooding extent and water surface elevations (presented in Section 5) with 24 inches of sea level rise are only slightly greater than expected with 12 inches of sea level rise. The flood extent maps are presented in Attachment A. The maps can be used to enhance the overall understanding of the flooding vulnerabilities at the core transportation assets within the Oakland Coliseum focus area.

Table 4: Mapped HEC-RAS Simulations

Mapping Scenario	Modeled Scenario
Mapping Scenario 1	MHHW + 100-year Peak Flow
	MHHW + 24” SLR + 100-year Peak Flow
Mapping Scenario 2	10-year Extreme Tide + 10-year Peak Flow
	10-year Extreme Tide + 24” SLR + 10-year Peak Flow
Mapping Scenario 3	10-year Extreme Tide + 100-year Peak Flow
	10-year Extreme Tide + 24” SLR + 100-year Peak Flow
Mapping Scenario 4	100-year Extreme Tide + 10-year Peak Flow
	100-year Extreme Tide + 24” SLR + 10-year Peak Flow

5. RESULTS

The following section provides an evaluation of the potential inundation throughout the focus area under various storm surge and peak flow conditions. The results are evaluated for Damon Slough (FEMA Line K_DS), Arroyo Viejo Creek (FEMA Line K_US), and Lion Creek (FEMA Line J). The results for Lion Creek are only presented downstream of the San Leandro Street crossing, since the configuration of the channel upstream of this location represents conditions prior to upstream improvements implemented after 2005. The locations of the HEC-RAS cross sections referenced through this section can be viewed in Figure 3.

From the HEC-RAS results, no flooding is expected to occur from Damon Slough during existing conditions until 100-year extreme tide levels are coupled with a 10-year peak flow event. The flows at the Coliseum Way bridge begins to surcharge, or flow at full capacity, once peak flows exceed a 100-year event during MHHW tide levels, but these flows still remain within the existing channel. The channel banks at Damon slough are overtopped during storm surge events with 12 and 24 inches of sea level rise when combined with extreme riverine discharges in the channel.

The tidal influence on flood levels with 12 and 24 inches of sea level rise is lessened with increasing upstream distance in Arroyo Viejo Creek, but any rise in upstream water levels contributes to backwater flooding and expose assets to saline waters. The results show that high peak flows have the greatest impact on flooding in this reach, and flooding occurs with a 50-year peak flow event, even during existing MHHW tide levels with no sea level rise. The greatest impact of sea level rise will be seen during the occurrence of a 100-year extreme tide level with 24 inches of sea level rise, where storm surge will have more impact on water levels upstream in the reach. Flooding at Arroyo Viejo Creek can be attributed to several factors; the reduced downstream conveyance capacity in Damon Slough during higher tide levels, the addition of peak flows discharging from Lion Creek during extreme rainfall events, and the undersized conveyance capacity of the channel itself.

Flooding without elevated tide levels also occurs in Lion Creek, where flows reach out into the floodplains above a 50-year peak flow event during current day MHHW tide levels. During the 12- and 24-inches of sea level rise scenarios, Lion Creek is flooded under most modeled storm events. The most severe flooding will occur during 24 inches of sea level rise and the occurrence of a 100-year extreme tide level. The culverts under the Amtrak rail crossing and adjacent service road crossing flow full during a 10-year peak flow event under current day MHHW tide levels. With the same scenario under 12 or 24 inches of sea level rise, the Amtrak crossing is flooded.

Table 5 presents an example key to interpreting the summary tables of water surface elevations reported at each modeled HEC-RAS section in Damon Slough (Table 6), Arroyo Viejo Creek (Table 7), and Lion Creek (Table 8). Specific details on the layout of the table are as follows:

- The cross section names are simplified from their original HEC-RAS station labels in order to identify the cross sections more easily (see Figure 3 for locations of modeled cross sections).
- For each cross section, the water surface elevation for each scenario is listed.
- Cross sections that are not flooded are shaded in light green.
- Cross sections that are flooded, but by a depth less than 1 foot, are shaded in yellow.
- Cross sections that are flooded by a depth greater than 1 foot, but less than 2 feet, are shaded in red.
- Cross sections that are flooded by a depth greater than 2 feet are shaded in purple.
- The controlling[6] left bank and right bank elevations that can convey channel flow without flooding of adjacent areas are listed. Where applicable, the location of flooding is listed (LB for left bank, and RB for right bank), along with the approximate depth of flooding. For example, if the left bank is flooded by a depth greater than 2 feet, but the right bank is only flooded by a depth lower than 2 feet, the designation *LB2; RB1* is listed.

Table 5: Example Key for HEC-RAS Summary Output Tables.

	Description
9.95 | 10.9	Controlling elevation of left and right bank (in FT-NAVD88); water surface above these elevations will flood adjacent areas outside of main channel.
9.17 -	Water surface elevation (in FT-NAVD88). Flow is contained below defined channel left/right bank, or controlling overbank elevation.
10.27 LB	Flow outside of controlling left channel overbank; flooding expected with depth <1ft
11.17 LB1; RB	Flow outside of controlling left channel overbank; flooding expected with depth between 1-2 feet. Flow outside of controlling right channel overbank; flooding expected with depth <1ft
12.28 LB2; RB1	Flow outside of controlling left channel overbank; flooding expected with depth >2ft. Flow outside of controlling right channel overbank; flooding expected with depth between 1-2 ft

[6] The controlling bank elevations for the purposes of this analysis are the elevations above the defined channel bank elevations when floodwaters will reach extensive portions of the floodplains. These elevations are greater than the bank elevations defined in the HEC-RAS model since flooding of the immediate overbanks does not necessary contribute to critical flooding of the adjacent areas. The channel bank elevations in the HEC-RAS model were defined as the approximate water surface elevation in the channel corresponding to a 10-year peak flow event.

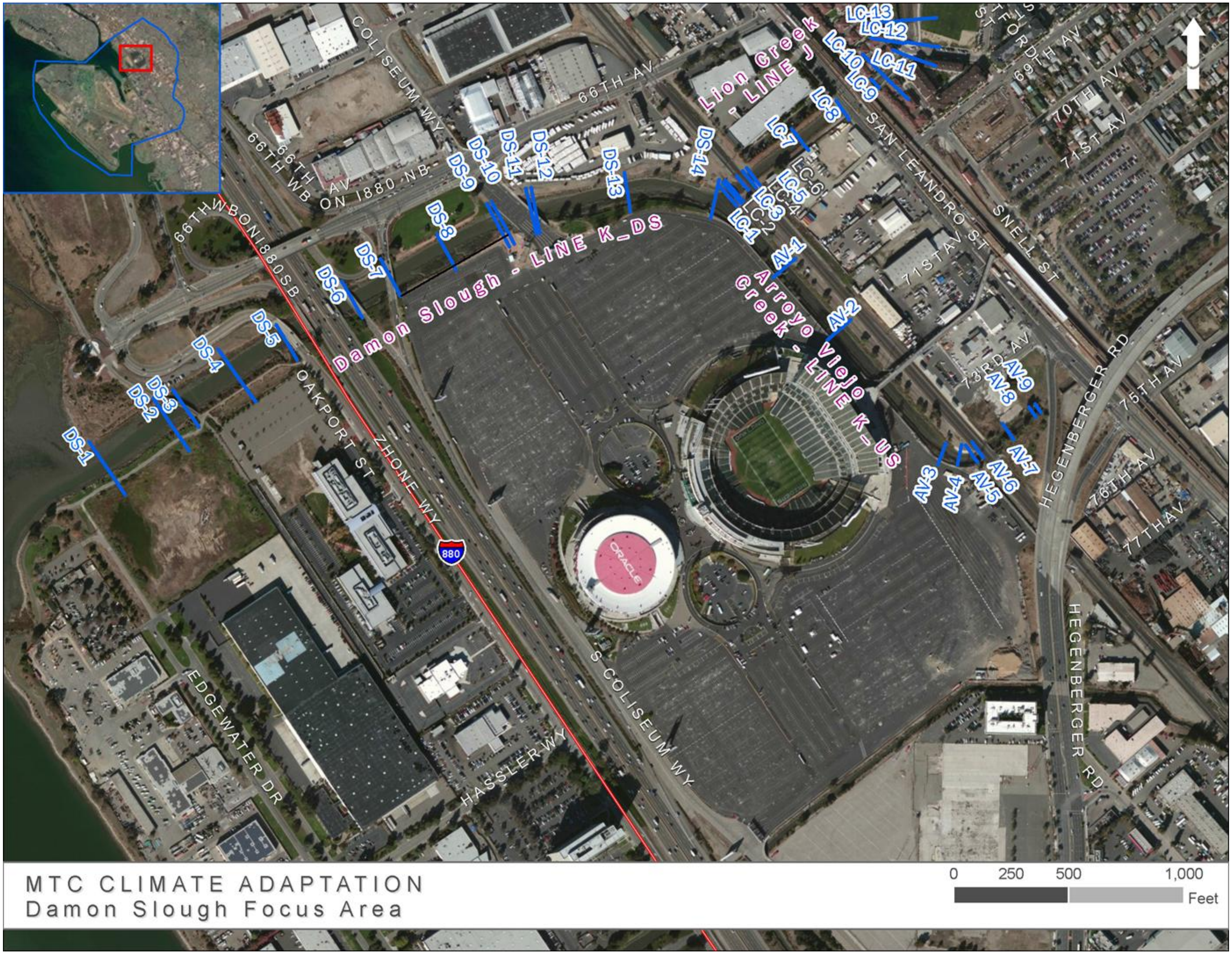

Figure 3: Locations of Modeled HEC-RAS Cross Sections

Table 6: HEC-RAS Results – Damon Slough (LINE K_DS)

<table>
<tr><th>RAS XS</th><th>0</th><th>340</th><th>432.89</th><th>697.86</th><th>961.66</th><th rowspan="3">I-880 Crossin g</th><th>1303.12</th><th>1496.96</th><th>1765.08</th><th>2020</th><th>2043.06</th><th rowspan="3">Coliseum Way Crossing</th><th>2180.26</th><th>2200</th><th>2590.03</th><th>2981.22</th></tr>
<tr><th>RAS XS</th><th>DS-1</th><th>DS-2</th><th>DS-3</th><th>DS-4</th><th>DS-5</th><th>DS-6</th><th>DS-7</th><th>DS-8</th><th>DS-9</th><th>DS-10</th><th>DS-11</th><th>DS-12</th><th>DS-13</th><th>DS-14</th></tr>
<tr><th>LB | RB Elev.</th><th>10.67 | 9.62</th><th>12.14 | 12.44</th><th>12.23 | 12.65</th><th>11.70 | 11.0</th><th>11.06 | 10.54</th><th>11.14 | 11.32</th><th>11.18 | 16.07</th><th>9.95 | 10.9</th><th>12.2 | 12.06</th><th>12.2 | 12.06</th><th>10.95 | 13.07</th><th>10.95 | 13.07</th><th>12.01 | 12.01</th><th>12.00 | 12.00</th></tr>
<tr><th>Scenario</th><th colspan="16">Water Surface Elevation (FT-NAV88)</th></tr>
<tr><td>MHHW + 10-year</td><td>6.61
-</td><td>6.84
-</td><td>6.99
-</td><td>7.14
-</td><td>7.31
-</td><td>-</td><td>7.56
-</td><td>7.69
-</td><td>7.88
-</td><td>8.11
-</td><td>8.13
-</td><td>-</td><td>8.27
-</td><td>8.28
-</td><td>8.48
-</td><td>8.87
-</td></tr>
<tr><td>+ 12" SLR</td><td>7.61
-</td><td>7.73
-</td><td>7.82
-</td><td>7.91
-</td><td>8.02
-</td><td>-</td><td>8.18
-</td><td>8.26
-</td><td>8.4
-</td><td>8.57
-</td><td>8.59
-</td><td>-</td><td>8.69
-</td><td>8.7
-</td><td>8.84
-</td><td>9.16
-</td></tr>
<tr><td>+ 24" SLR</td><td>8.61
-</td><td>8.68
-</td><td>8.73
-</td><td>8.79
-</td><td>8 .86
-</td><td>-</td><td>8.95
-</td><td>9.01
-</td><td>9.1
-</td><td>9.22
-</td><td>9.23
-</td><td>-</td><td>9.44
-</td><td>9.44
-</td><td>9.52
-</td><td>9.74
-</td></tr>
<tr><td>MHHW + 100-year</td><td>6.61
-</td><td>7.15
-</td><td>7.46
-</td><td>7.73
-</td><td>8.03
-</td><td>-</td><td>8.4
-</td><td>8.59
-</td><td>8.85
-</td><td>9.2
-</td><td>9.21
-</td><td>-</td><td>9.74
-</td><td>9.76
-</td><td>9.89
-</td><td>10.32
-</td></tr>
<tr><td>+ 12" SLR</td><td>7.61
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-</td><td>8.28
-</td><td>8.5
-</td><td>-</td><td>8.78
-</td><td>8.93
-</td><td>9.15
-</td><td>9.45
-</td><td>9.46
-</td><td>-</td><td>10
-</td><td>10.02
-</td><td>10.12
-</td><td>10.5
-</td></tr>
<tr><td>+ 24" SLR</td><td>8.61
-</td><td>8.77
-</td><td>8.91
-</td><td>9.02
-</td><td>9.17
-</td><td>-</td><td>9.37
-</td><td>9.47
-</td><td>9.64
-</td><td>9.88
-</td><td>9.89
-</td><td>-</td><td>10.45
-</td><td>10.46
-</td><td>10.53
-</td><td>10.84
-</td></tr>
<tr><td>10-year Extreme Tide + 10-year</td><td>8.84
-</td><td>8.9
-</td><td>8.95
-</td><td>9
-</td><td>9.06
-</td><td>-</td><td>9.15
-</td><td>9.2
-</td><td>9.28
-</td><td>9.39
-</td><td>9.4
-</td><td>-</td><td>9.61
-</td><td>9.62
-</td><td>9.68
-</td><td>9.88
-</td></tr>
<tr><td>+ 12" SLR</td><td>9.84
RB</td><td>9.87
-</td><td>9.91
-</td><td>9.94
-</td><td>9.98
-</td><td>-</td><td>10.04
-</td><td>10.07
-</td><td>10.12
-</td><td>10.2
-</td><td>10.2
-</td><td>-</td><td>10.44
-</td><td>10.44
-</td><td>10.47
-</td><td>10.6
-</td></tr>
<tr><td>+ 24" SLR</td><td>10.84
LB; RB1</td><td>10.86
-</td><td>10.89
-</td><td>10.91
-</td><td>10.93
RB</td><td>-</td><td>10.97
-</td><td>10.99
-</td><td>11.02
LB1; RB</td><td>11.08
-</td><td>11.08
-</td><td>-</td><td>11.33
LB</td><td>11.33
LB</td><td>11.34
-</td><td>11.43
-</td></tr>
<tr><td>10-year Extreme Tide + 100-year</td><td>8.84
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-</td><td>9.11
-</td><td>9.21
-</td><td>9.35
-</td><td>-</td><td>9.53
-</td><td>9.62
-</td><td>9.78
-</td><td>10
-</td><td>10.01
-</td><td>-</td><td>10.58
-</td><td>10.59
-</td><td>10.65
-</td><td>10.94
-</td></tr>
<tr><td>+ 12" SLR</td><td>9.84
RB</td><td>9.92
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-</td><td>10.08
-</td><td>10.17
-</td><td>-</td><td>10.29
-</td><td>10.36
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LB</td><td>10.64
-</td><td>10.64
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LB</td><td>11.23
LB</td><td>11.27
-</td><td>11.49
-</td></tr>
<tr><td>+ 24" SLR</td><td>10.84
LB; RB1</td><td>10.89
-</td><td>10.95
-</td><td>11
-</td><td>11.06
RB</td><td>-</td><td>11.14
-</td><td>11.18
-</td><td>11.26
LB1; RB</td><td>11.38
-</td><td>11.39
-</td><td>-</td><td>11.99
LB1</td><td>12
LB1</td><td>12.01
-</td><td>12.17
LB; RB</td></tr>
<tr><td>100-year Extreme Tide + 10-year</td><td>10.01
-</td><td>10.04
-</td><td>10.08
-</td><td>10.11
-</td><td>10.14
-</td><td>-</td><td>10.19
-</td><td>10.22
-</td><td>10.27
LB</td><td>10.35
-</td><td>10.35
-</td><td>-</td><td>10.58
-</td><td>10.59
-</td><td>10.61
-</td><td>10.74
-</td></tr>
<tr><td>+ 12" SLR</td><td>11.01
LB; RB1</td><td>11.03
-</td><td>11.05
-</td><td>11.07
RB</td><td>11.1
LB; RB</td><td>-</td><td>11.13
-</td><td>11.15
-</td><td>11.18
LB1; RB</td><td>11.23
-</td><td>11.24
-</td><td>-</td><td>11.48
LB</td><td>11.49
LB</td><td>11.5
-</td><td>11.58
-</td></tr>
<tr><td>+ 24" SLR</td><td>12.01
LB1;
RB2</td><td>12.02
-</td><td>12.04
-</td><td>12.05
LB; RB1</td><td>12.07
LB; RB1</td><td>-</td><td>12.09
LB; RB</td><td>12.1
LB</td><td>12.12
LB2; RB1</td><td>12.16
RB</td><td>12.16
RB</td><td>-</td><td>12.42
LB1</td><td>12.42
LB1</td><td>12.42
LB; RB</td><td>12.48
LB; RB</td></tr>
</table>

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Table 7: HEC-RAS Results – Arroyo Viejo Creek (LINE K_US)

RAS XS	3416.43	3744.86	4473.12	4547.99	4607.95	4639.46	Amtrak Crossing	4790	4921.3	4951.28
RAS XS	AV-1	AV-2	AV-3	AV-4	AV-5	AV-6		AV-7	AV-8	AV-9
LB | RB Elev.	10.4 | 10.65	11.02 | 10.83	11.86 | 10.73	12.09 | 10.67	10.74 | 10.26	11.11 | 10.86		12.53 | 11.27	12.97 | 12.97	17.02 | 12.51
Scenario	**Water Surface Elevation (FT-NAV88)**									
MHHW + 10--year	9.38 -	9.55 -	9.92 -	10.01 -	10.01 -	9.99 -	-	10.26 -	10.36 -	10.31 -
+ 12" SLR	9.6 -	9.75 -	10.08 -	10.16 -	10.16 -	10.15 -	-	10.39 -	10.48 -	10.42 -
+ 24" SLR	10.07 -	10.19 -	10.44 -	10.51 -	10.5 RB	10.49 -	-	10.69 -	10.76 -	10.7 -
MHHW + 100-year	10.89 LB; RB	11.13 LB; RB	11.59 RB	11.69 RB1	11.67 LB1; RB	11.63 LB; RB	-	12.03 RB	12.02 -	11.76 -
+ 12" SLR	11.02 LB; RB	11.25 LB; RB	11.67 RB	11.77 RB1	11.76 LB1; RB	11.72 LB; RB	-	12.09 RB	12.07 -	11.81 -
+ 24" SLR	11.29 LB; RB	11.48 LB; RB	11.86 RB1	11.94 RB1	11.93 LB1; RB	11.89 LB1; RB	-	12.22 RB	12.19 -	11.93 -
10-year Extreme Tide + 10-year	10.2 -	10.3 -	10.55 -	10.61 -	10.6 RB	10.59 -	-	10.78 -	10.84 -	10.78 -
+ 12" SLR	10.83 LB; RB	10.91 RB	11.08 RB	11.12 RB	11.12 LB; RB	11.1 RB	-	11.26 -	11.29 -	11.23 -
+ 24" SLR	11.59 LB1; RB	11.64 LB; RB	11.75 RB1	11.78 RB1	11.78 RB1	11.77 LB; RB	-	11.87 RB	11.87 -	11.8 -
10-year Extreme Tide + 100-year	11.37 LB; RB	11.56 LB; RB	11.91 LB; RB1	12 RB1	11.99 LB1; RB1	11.95 LB; RB1	-	12.26 RB	12.23 -	11.97 -
+ 12" SLR	11.82 LB1; RB	11.98 LB; RB1	12.26 LB; RB1	12.32 LB; RB1	12.31 LB1; RB2	12.28 LB1; RB1	-	12.53 RB1	12.47 -	12.22 -
+ 24" SLR	12.42 LB2; RB1	12.54 LB1; RB	12.74 LB; RB2	12.79 LB; RB2	12.78 LB2; RB2	12.75 LB1; RB1	-	12.94 LB; RB1	12.86 -	12.62 RB
100-year Extreme Tide + 10-year	10.95 LB; RB	11.03 LB; RB	11.19 RB	11.23 RB	11.22 LB; RB	11.21 LB; RB	-	11.35 RB	11.38 -	11.31 -
+ 12" SLR	11.73 LB1; RB	11.78 LB; RB	11.88 LB; RB1	11.91 RB1	11.9 LB1; RB1	11.89 LB; RB1	-	11.99 RB	11.98 -	11.92 -
+ 24" SLR	12.58 LB2; RB1	12.62 LB1; RB	12.68 LB; RB1	12.7 LB; RB2	12.7 LB1; RB2	12.69 LB1; RB	-	12.74 LB; RB1	12.73 -	12.66 RB

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Table 8: HEC-RAS Results – Lion Creek (LINE J)

RAS XS	65	87	90	98	146	160	179	200	453	667
RAS XS	LC-1	LC-2	Bridge	LC-3	LC-4	Bridge	LC-5	LC-6	LC-7	LC-8
LB | RB Elev.	13.12 | 13.24	13.12 | 13.24		13.16 | 13.21	10.24 | 10.97		10.16 | 10.23	12.00 | 12.00	12.78 | 12.49	13.00 | 13.00
Scenario	**WSEL (FT-NAV8)**									
MHHW + 10--year	9.16 -	9.17 -	-	9.19 -	9.19 -	-	9.3 -	9.31 -	9.39 -	9.48 -
+ 12" SLR	9.42 -	9.42 -	-	9.49 -	9.49 -	-	9.61 -	9.62 -	9.69 -	9.76 -
+ 24" SLR	9.93 -	9.94 -	-	10.03 -	10.02 -	-	10.16 -	10.17 -	10.22 -	10.28 -
MHHW + 100-year	10.72 -	10.73 -	-	10.99 -	10.98 RB	-	11.37 LB1; RB1	11.4 -	11.47 -	11.54 -
+ 12" SLR	10.88 -	10.89 -	-	11.15 -	11.14 LB; RB	-	11.55 LB1; RB1	11.58 -	11.64 -	11.71 -
+ 24" SLR	11.17 -	11.18 -	-	11.46 -	11.45 LB1; RB	-	11.8 LB1; RB1	11.83 -	11.88 -	11.94 -
10-year Extreme Tide + 10-year	10.07 -	10.07 -	-	10.16 -	10.16 -	-	10.30 RB	10.31 -	10.36 -	10.41 -
+ 12" SLR	10.74 -	10.75 -	-	10.86 -	10.86 LB	-	11.01 LB, RB	11.02 -	11.06 -	11.10 -
+ 24" SLR	11.54 -	11.54 -	-	11.67 -	11.66 LB1; RB	-	11.8 LB1; RB1	11.81 -	11.83 -	11.86 -
10-year Extreme Tide + 100-year	11.26 -	11.27 -	-	11.55 -	11.54 LB1; RB	-	11.88 LB1; RB1	11.91 -	11.96 -	12.02 -
+ 12" SLR	11.75 -	11.75 -	-	12.06 -	12.04 LB1; RB1	-	12.31 LB2; RB2	12.35 LB, RB	12.39 -	12.44 -
+ 24" SLR	12.37 -	12.38 -		12.7 -	12.69 LB2; RB1	-	12.89 LB2; RB2	12.92 LB, RB	12.96 RB	12.99 -
100-year Extreme Tide + 10-year	10.87 -	10.88 -	-	10.99 -	10.99 LB; RB	-	11.17 LB1, RB	11.18 -	11.22 -	11.25 -
+ 12" SLR	11.68 -	11.68 -	-	11.81 -	11.81 LB1; RB	-	11.93 LB1, RB1	11.95 -	11.97 -	11.99 -
+ 24" SLR	12.55 -	12.55 -	-	12.70 -	12.69 LB2; RB1	-	12.78 LB2; RB2	12.79 LB; RB	12.81 LB; RB	12.82 -

Although the water surface elevations reported at each HEC-RAS cross section provide valuable information about the interdependencies between the various boundary conditions and channel hydraulics that result in flood levels, it is challenging to directly translate these results to assess the extent of inland flooding. This assessment can be supplemented by reviewing the flood maps presented in Attachment A in detail. Using a combination of the HEC-RAS model summary and the flood mapping, the scenarios when the channels and core assets are first exposed to flooding are presented in Table 9 and Table 10 provide insight into the timing of when the operations of the assets can be impacted. The timing of flooding at the stream channels (Table 9) is presented separately from the timing of flooding at the locations of the key assets (Table 10). This is because assets are not necessarily flooded by a directly adjacent tributary to until a later scenario, so it is helpful to identify these areas and scenarios separately. For example, areas adjacent to Damon Slough (i.e., the Coliseum Complex parking area) can be flooded from upstream sources prior to flooding in the Damon Slough channel itself. The scenario of when the assets are first exposed to flooding from only riverine discharge, and also from the combined effects of riverine and coastal storm surge events, is also presented. Note that peak flow rates between the 10- and 100-year events are listed (including 25- and 50-year events[7]), in an effort to provide more useful scenarios from which to formulate adaptation strategies.

Note that not all of the scenarios presented in Table 9 and Table 10 were mapped. As stated in Section 4, limited differences were observed in the flooding extents between 12 and 24 inches of sea level rise, therefore only the existing conditions and 24 inches of sea level rise scenarios were mapped. The following sections provides a discussion on of the timing of flooding and impacts to the focus area under existing conditions also sea level rise.

Table 9: Timing of Flooding at Stream Channels in Focus Area

Asset	Scenario	Timing of Flooding			
		From Riverine		From Coastal and Riverine	
		Extreme Tide	Peak Flow	Extreme Tide	Peak Flow
Damon Slough	Existing	-	-	100-Year	10-Year*
	12-inch SLR	-	-	10-Year	10-Year*
	24-inch SLR	-	-	10-Year	10-Year*
Arroyo Viejo Creek	Existing	MHHW	50-Year	10-Year	25-Year
	12-inch SLR	MHHW	50-Year	10-Year	10-Year
	24-inch SLR	MHHW	25-Year	10-Year	10-Year
Lion Creek	Existing	MHHW	50-Year	10-Year	25-Year*
	12-inch SLR	MHHW	25-Year*	10-Year	10-Year*
	24-inch SLR	MHHW	25-Year*	10-Year	10-Year*

*Flooding occurs at isolated transects, but is not yet extensive.

[7] The 25-year flowrate used in the HEC-RAS model is as follows: (Lion Creek - 1,831, Arroyo Viejo Creek - 2,000cfs, Damon Slough - 3,100cfs). The 50-year flowrate used in the HEC-RAS model is as follows: (Lion Creek - 2,400cfs, Arroyo Viejo Creek – 2,800cfs, Damon Slough - 3,600cfs).

Table 10: Timing of Flooding at Key Assets in Focus Area

Asset	Scenario	Timing of Flooding			
		From Riverine		From Coastal and Riverine	
		Extreme Tide	Peak Flow	Extreme Tide	Peak Flow
I-880 Crossing[1]	Existing	-	-	-	-
	12-inch	-	-	100-Year	10-Year
	24-inch	MHHW	100-Year	10-Year	10-Year
Coliseum Complex	Existing	MHHW	50-Year	10-Year	10-Year
	12-inch	MHHW	50-Year	10-Year	10-Year
	24-inch	MHHW	25-Year	10-Year	10-Year
Coliseum Amtrak Station / Rail Corridor	Existing	MHHW	50-Year	10-Year	25-Year
	12-inch	MHHW	50-Year	10-Year	25-Year
	24-inch	MHHW	25-Year	10-Year	10-Year
Coliseum BART Station	Existing	MHHW	100-Year	10-Year	100-Year
	12-inch	MHHW	100-Year	10-Year	10-Year
	24-inch	MHHW	100-Year	10-Year	10-Year
OAK Airport Connector	Existing	MHHW	50-Year*	10-Year	25-Year*
	12-inch	MHHW	50-Year*	10-Year	25-Year*
	24-inch	MHHW	50-Year*	10-Year	10-Year*

*Flooding occurs at isolated transects, but is not yet extensive.

[1] Flooding of roadway adjacent to Damon Slough occurs when water levels reach 10.5’ NAVD (approx.).

5.1. Existing Conditions (No Sea Level Rise)

From the HEC-RAS modeling results, flooding occurs throughout the focus area during existing conditions, prior to any increase in daily tide conditions due to sea level rise. The following provides detail on the timing of flooding and the processes that contribute to the flooding during existing conditions.

Stream Channels

Damon Slough

- Under existing MHHW tide conditions in the absence of sea level rise, there is no flooding in the Damon Slough channel even at a 100-year peak flow event. Limited flooding occurs during storm surge conditions when a 10-year peak flow event coincides with a 100-year extreme tide. This scenario was the worst case scenario that was modeled. The most severe flooding in this reach is primarily driven by higher Bay water levels during extreme storm surge conditions, but only when coupled with an extreme peak flow event. Mitigation measures need to consider the combined effects of downstream flooding from storm surge and upstream flooding from rainfall driven runoff events that occur simultaneously.

Arroyo Viejo Creek

- Under existing MHHW tide conditions in the absence of sea level rise, there is limited flooding at one section in the channel during peak flows above the 25-year event, but critical flooding occurs above a 50-year peak flow event. During storm surge conditions at the 10-year extreme tide level, flooding begins at a 25-year peak flow, but extensive flooding occurs during a 50-year peak flow event. The most severe flooding in this reach during existing conditions is primarily driven from rainfall runoff events, but is increased when these events occur during storm surge conditions. Floodwaters in Arroyo Viejo Creek will also travel overland to flood areas adjacent to Damon Slough at the Coliseum park area. Measures to mitigate flooding during existing conditions should first consider strategies in the watershed or directly at the channel banks.

Lion Creek

- Under existing MHHW tide conditions in the absence of sea level rise, flooding occurs at a 50-year peak flow event. During storm surge conditions at or above the 10-year extreme tide level, flooding begins at a 25-year peak flow event, but extensive flooding occurs during a 100-year peak flow event. Flooding is more severe with a 100-year peak flow event during a 10-year extreme tide, than a 10-year peak flow event during a 100-year extreme tide, meaning that the most severe flooding occurs from heavy rainfall events, but flooding is also intensified during storm surge events.

Key Assets

I-880 Crossing

- No flooding over the I-880 crossing over Damon Slough or adjacent roadway areas is expected to occur during existing conditions. However, further modeling is necessary to verify these findings, since the I-880 crossing was not modeled in HEC-RAS.

Coliseum Complex

- Flooding occurs throughout the Coliseum Complex during MHHW tide conditions with a 50- to 100-year peak flow rate. Under coastal storm surge, flooding can also occur with a 10-year extreme tide combined with a 25-year peak flow event. Flooding at low-lying areas at the parking lot is not expected to occur directly from Damon Slough, but via overland flow pathways from Arroyo Viejo Creek during these peak flow events. The most extensive flooding in the parking lot area is expected during a 100-year extreme tide level combined with a 10-year peak flow event. Protection of this asset should consider both higher water levels during storm surge conditions and watershed flooding.

Coliseum Amtrak Station / Rail Corridor

- In the absence of storm surge, the Coliseum Amtrak Station and adjacent rail corridor is vulnerable to flooding beginning at a 50-year peak flow event. During coastal storm surge, flooding can also occur with a 100-year extreme tide combined with a 25-year peak flow event. Although the Amtrak Station passenger platform may not be flooded during all scenarios, the operations of this asset are sensitive to flooding of the surrounding railway and any exposure of the electrical components to floodwaters. The rail crossings over Arroyo Viejo and Lion Creek are especially vulnerable to flooding during all scenarios, but the crossing over Arroyo Viejo creek was not modeled in HEC-RAS, and this constriction should be included if more detailed modeling work is conducted. Protection of this asset should consider both higher water levels during storm surge conditions and watershed flooding.

Coliseum BART Station

- The Coliseum BART station is the most vulnerable during rainfall runoff events, and is exposed to flooding from Lion Creek via an overland flow pathway along San Leandro Street and also just north of San Leandro Street. Although the passenger platform and service corridor is elevated, there are existing power utilities and pedestrian access points located at existing ground elevations, which are vulnerable to exposure prior to the BART station itself. Under existing MHHW tide conditions, flooding can occur during 100-year peak flow event. During coastal storm surge, more severe flooding can occur with a 10-year extreme tide combined with a 100-year peak flow event. Storm surge conditions in the Bay have less of an impact in this area than flooding from watershed runoff. Flooding of the adjacent roadways and parking lot can occur during scenarios earlier than a 100-year peak flow event without storm surge, and may cause disruptions that will impact the overall level of service of the system. Watershed flooding should be addressed to mitigate impacts to this asset.

Oakland Airport Connector

- Although the pedestrian area of the new Oakland Airport Connecter is elevated, there are vulnerable power facilities and utilities located at ground elevations. The location of the new Oakland Airport Connector is vulnerable to flooding during a 50-year peak flow event in the surrounding channels, even in the absence of storm surge conditions. During coastal storm surge, overland flooding can also occur with a 10-year extreme tide combined with a 25-year peak flow event. The Airport Connector railway eventually enters ground elevations outside of this focus area boundary, and flooding at this location will cause disruptions in service to the overall transit system in this area and should be investigated.

5.2. Future Conditions (12-inches of Sea Level Rise)

With 12 inches of sea level rise at the downstream tidal boundary, flooding will be increased in all areas. In some areas, flooding will occur more frequently with smaller peak flow events under the same coastal storm surge conditions with sea level rise. The areas that are the farthest upstream from the tidal influence will see the least impact from rising tides, but will still experience worsened flooding due to the rising baseflow elevation in the stream channels.

Stream Channels

Damon Slough

- Damon Slough is still able to convey the 100-year peak flow event within the channel in the absence of storm surge conditions in the Bay with 12 inches of sea level rise. However, flooding now occurs during smaller and more frequent storm surge events – a 10-year extreme tide when combined with a 10-year peak flow event. The greatest influence on downstream water levels is storm surge, so the addition of 12 inches of sea level rise on the 100-year extreme tide level can flood these areas by a depth greater than 1-foot. The upstream portions of Damon Slough are flooded by less than 1-foot with either a 10-year peak flow during a 100-year extreme tide or a 100-year peak flow during a 10-year extreme tide, meaning that any combination of riverine and storm surge can now cause flooding during the 12 inch sea level rise scenario. This was not the case with no sea level rise. The primary driver for flooding in the downstream reaches are extreme tide levels during storm surge conditions, and the primary driver for flooding in the upstream reaches are peak flows during rainfall runoff events.

Arroyo Viejo Creek

- In Arroyo Viejo Creek, flooding first occurs during a 50-year peak flow event during MHHW tide conditions with 12 inches of sea level rise. Flooding also occurs during a 50-year peak flow event with MHHW tide conditions with no sea level rise, but with 12 inches of sea level rise, the downstream portions will experience greater depths of flooding. Under coastal storm surge with 12 inches of sea level rise, Arroyo Viejo Creek floods during a 10-year extreme tide level combined with a 10-year peak flow event, compared to flooding during existing conditions from a 10-year extreme tide combined with a 25-year peak flow event. Although adding 12 inches of sea level rise at the downstream boundary does not translate to an increase of 12 inches in the upstream baseflow elevation in this reach, the tidal influence is strong enough to create additional flooding in upstream areas during storm surge conditions.

Lion Creek

- In Lion Creek, 12 inches of sea level rise allows flooding to occur more frequently with smaller peak flow events. During MHHW tide conditions, areas adjacent to Lion Creek now flood at a 25-year peak flow event, and with coastal storm surge, flooding now occurs at a 10-year extreme tide level combined with a 10-year peak flow event. Although adding 12 inches of sea level rise at the downstream boundary does not translate to an increase of 12 inches in the upstream baseflow elevation in this reach, the tidal influence is strong enough to create additional flooding in upstream areas during storm surge conditions.

Key Assets

I-880 Crossing

- With 12 inches of sea level rise, no flooding over the I-880 roadway is expected to occur unless there are elevated Bay water levels during storm surge conditions. Flooding at I-880 due to 12 inches of sea level rise is expected to occur when a 100-year extreme tide level is combined with a 10-year peak flow rate. The deck of the bridge crossing over Damon Slough and portions of the adjacent roadways are vulnerable to flooding during this scenario.

Coliseum Complex

- Flooding occurs throughout the Coliseum Complex during MHHW tide conditions with 12 inches of sea level rise and a 50-year peak flow rate, the same as existing conditions with no sea level rise. Flooding at low-lying areas at the parking lot is from overland flow pathways from Arroyo

Viejo Creek during these peak flow events. With 12 inches of sea level rise flooding also comes directly from overtopping over Damon Slough starting from a 10-year extreme tide combined with a 25-year peak flow event. The most extensive flooding in the parking lot area is expected during a 100-year storm surge combined with a 10-year peak flow event.

Coliseum Amtrak Station / Rail Corridor

- With 12 inches of sea level rise, the Coliseum Amtrak Station and adjacent rail corridor is exposed to flooding starting at a 50-year peak flow event during MHHW tide conditions, the same as with no sea level rise. With coastal storm surge, flooding can also first occur during a 10-year extreme tide when combined with a 25-year peak flow event, the same as with no sea level rise.

Coliseum BART Station

- Flooding can occur during peak flows of a 100-year event under MHHW tide conditions with 12 inches of sea level rise, the same as with no sea level rise. With coastal storm surge, flooding can also first occur during a 10-year extreme tide when combined with a 10-year peak flow event. This is a smaller peak flow than the 25-year peak flow required to cause flooding with a 10-year extreme tide with no sea level rise.

Oakland Airport Connector

- Under 12 inches of sea level rise, the new Oakland Airport Connector can be exposed to flooding at the same scenarios with no sea level rise, but at a greater depth.

5.3. Future Conditions (24-inches of Sea Level Rise)

With 24 inches of sea level rise at the downstream tidal boundary, extensive flooding is expected throughout most of the focus areas during coincident peak flows in the stream channels. Flooding is expected to occur more frequently than with 12 inches of sea level rise from both smaller peak flow events and lower levels of extreme tides. The areas that are the farthest upstream from the tidal influence will see the least impact from rising tides, but additional flooding in new areas is now expected. Greater than 2 feet of flooding can be expected in many areas with a 10-year peak flow during a 100-year extreme tide or a 100-year peak flow during a 10-year extreme tide.

Stream Channels

Damon Slough

- Damon Slough is still able to convey the 100-year peak flow event within the channel in the absence of storm surge conditions in the Bay during 24 inches of sea level rise. However, during storm surge conditions (10- and 100-year extreme tide), additional portions of the channel now begin to flood at a 10-year peak flow rate. The greatest influence on downstream water levels is storm surge, so the addition of 24 inches of sea level rise on the 100-year extreme tide level can flood these areas by a depth greater than 2-feet. The upstream portions of Damon Slough are flooded by more than 1-foot with either a 10-year peak flow during a 100-year extreme tide or a 100-year peak flow during a 10-year extreme tide, meaning that any combination of the most extreme tide or peak flow event can now cause extensive flooding during 24 inches of sea level rise. Flooding will increase significantly compared to that expected during 12 inches of sea level rise.

Arroyo Viejo Creek

- With 24 inches of sea level rise flooding is now expected to occur with a 25-year peak flow event during MHHW tide conditions, whereas the channel can still convey this scenario under 12 inches of sea level rise. Flooding still occurs with a 10-year peak flow during a 10-year storm surge. Portions of the channel are also flooded by greater than 2 feet during 24 inches of sea level rise, with a 10-year peak flow during a 100-year extreme tide or a 100-year peak flow during a 10-year extreme tide. At these scenarios, additional areas upstream of Hegenberger Road are now flooded. Although adding 24 inches of sea level rise at the downstream boundary does not translate to an increase of 24 inches in the upstream baseflow elevation in this reach, the tidal influence is strong enough to create additional flooding in upstream areas during storm surge conditions.

Lion Creek

- In Lion Creek, flooding during 24 inches of sea level rise is now more severe and additional areas will be flooded upstream of the Amtrak crossing. The critical scenario of flooding is still the 10-year peak flow combined with a 10-year extreme tide. Although adding 24 inches of sea level rise at the downstream boundary does not translate to an increase of 24 inches in the upstream baseflow elevation in this reach, the tidal influence is strong enough to create additional flooding in upstream areas during storm surge conditions.

Key Assets

I-880 Crossing

- With 24 inches of sea level rise, flooding at I-880 is still only vulnerable to flooding during storm surge conditions, at a greater frequency than during 12 inches of sea level rise. The critical scenario of flooding is now the 10-year extreme tide level combined with a 10-year peak flow. Further modeling is necessary to verify these findings.

Coliseum Complex

- With 24 inches of sea level rise, portions of the parking lot are flooded with a 25-year peak flow event under MHHW tide conditions, compared to a 50-year peak flow event with 12 inches sea level rise. Direct flooding comes directly from overtopping over Damon Slough starting from a 10-year peak flow during a 10-year extreme tide event. Up to 2-feet of flooding is expected with a 10-year peak flow during a 100-year extreme tide or a 100-year peak flow during a 10-year extreme tide. The most extensive flooding in the parking lot area is expected during a 100-year storm surge coupled with a 10-year peak flow event.

Coliseum Amtrak Station / Rail Corridor

- With 24 inches of sea level rise, the Coliseum Amtrak Station and adjacent rail corridor is exposed to flooding starting at a 25-year peak flow event during MHHW tide conditions. Flooding can also first occur with a 10-year extreme tide combined with a 10-year peak flow event, compared to a 10-year extreme tide with a 25-year peak flow during 12 inches of sea level rise. Flooding is expected at all combinations of extreme tide levels coupled with peak flow events under this sea level rise scenario.

Coliseum BART Station

- Flooding at the BART station and adjacent areas can occur during peak flows at a 100-year event under MHHW tide conditions with 24 inches of sea level rise, the same as with 12 inches of sea level rise. With coastal storm surge, flooding can occur with a 10-year extreme tide combined with a 10-year peak flow event, the same as with 12 inches of sea level rise.

Oakland Airport Connector

- With 24 inches of sea level rise, the new Oakland Airport Connector is vulnerable to flooding during a 50-year peak flow event in the surrounding channels, even in the absence of storm surge conditions. This is same as 0 and 12 inches of sea level rise. Flooding can also first occur with a 10-year extreme tide combined with a 10-year peak flow event, compared to a 10-year extreme tide with a 25-year peak flow during 12 inches of sea level rise.

6. SUMMARY

This analysis builds upon the work completed during the previous MTC Vulnerability and Risk Assessment Project, by providing a more detailed analysis of potential inundation by sea level rise and storm surge coupled with riverine flood conditions in the selected focus area. The current Pilot Study shows inundation of several areas during 36 inches of sea level rise (or a storm surge scenario that results in a similar level of inundatio*n)*, and nearly the entire focus area is inundated with 48 inches of sea level rise. These results do not consider the additional impact of riverine-induced flooding due to precipitation events. To evaluate these impacts, the existing HEC-RAS model provided by ACFCWCD was used to simulate a variety of storm surge and peak flow scenarios, and flood extent maps were created to supplement the analysis.

Flooding does not occur in the Damon Slough channel unless peak flow events from rainfall driven runoff occur during periods of coastal storm surge. Under existing conditions with no sea level rise, flooding can occur during storm surge conditions when a 100-year extreme tide level is combined with a 10-year peak flow event. With sea level rise of 12 or 24 inches, a similar level of flooding can occur more frequently with a lower (10-year) extreme tide combined with the same 10-year peak flow event. Flooding at I-880 will being to occur during storm surge conditions at 12 inches of sea level rise when a 100-year extreme tide is combined with a 10-year peak flow, and will occur more frequently during 24 inches of sea level rise at a lower (10-year) extreme tide level combined with the same 10-year peak flow rate. The most severe flooding at Damon Slough and the adjacent assets is primarily driven by coastal storm surge.

Flooding in Arroyo Viejo Creek is expected to occur from a 50-year peak flow event occurring during current day MHHW tide conditions, which exposes the Coliseum Complex, Coliseum BART Station, Coliseum Amtrak Station, and the Oakland Airport Connector Station to flooding. A similar level of flooding is expected during 12 inches of sea level rise, but with 24 inches of sea level rise, the channel can flood with only a 25-year peak flow event during MHHW tide conditions. With elevated tide levels (during an El Niño winter, for example), all of the core assets could be exposed to flooding during smaller peak flow events that occur more frequently. During existing conditions, Arroyo Viejo Creek can flood from a 10-year extreme tide combined with a 25-year peak flow event. With 12 inches of sea level rise, Arroyo Viejo Creek will flood more frequently with a 10-year extreme tide combined with a 10-year peak flow event. With 24 inches, this timing of flooding will remain the same, but the depth of flooding will increase. The most severe flooding in Arroyo Creek is primarily driven from watershed runoff, but is increased by higher Bay water levels.

Lion Creek also experiences flooding during existing conditions, and will also experience more frequent flooding with sea level rise. With 12 and 24 inches of sea level rise, Lion Creek will flood with a smaller (25-year) peak flow event during MHHW tide conditions, compared to a 50-year peak flow event during MHHW tide conditions with no sea level rise. Lion Creek will also flood more frequently from coastal storm surge events with 12 and 24 inches of sea level rise, with a 10-extreme tide combined with a 10-year peak flow event, compared to a 10-year extreme tide with no sea level rise combined with a 25-year peak flow event. The most severe flooding in Lion Creek is primarily driven from watershed flooding, but is increased by higher Bay water levels.

From this analysis, it is clear that the timing for implementing adaptation strategies to protect the core assets from exposure to flooding is now, during existing conditions, prior to any increases in sea level. Sea level rise of 12 and 24 inches will increase the severity of flooding in areas already flooded during existing conditions, regardless if the frequency of flooding increases or not. It will be important for adaptation strategies to consider the impacts of riverine discharges on flood levels, since similar levels to permanent inundation during 48 inches of sea level rise and above can already be experienced during existing conditions with certain occurrences of storm surge and peak flow events. Sea level rise alone may not immediately impact the assets in this focus area, but the rising tidal boundary will allow flooding to occur at more frequent intervals from smaller magnitudes of storm surge and peak flow events.

Understanding the flood dynamics with the modeling of extreme events and developing more detailed flood maps will provide valuable information for developing adaptation strategies for the vulnerable assets in this focus area. Some of the next steps that can be taken to further inform the planning process are provided in the following section.

7. POTENTIAL ADAPTATION MEASURES

The Damon Slough focus area will require multiple adaptation measures to prevent current and future flooding and inundation from both riverine and coastal extreme events. The combined effects of riverine and coastal flooding pose a greater impact on the system than only considering permanent inundation from sea level rise. As a part of the overall MTC Climate Adaptation Pilot Project, several adaptation strategies have been outlined to address the vulnerabilities identified within the Damon Slough focus area. The strategies are designed to protect the current location of key assets, and implementing policy changes to prevent future development in areas that are vulnerable to future sea level rise should be considered. The strategies outlined below could be implemented to help reduce existing and future flood risks.

7.1. Tide Gate (Damon Slough)

To provide protection for the Coliseum area from rising sea levels, a tide gate can be installed in the Damon Slough channel just downstream of the I-880 crossing. A tide gate can be used to control the maximum tide levels in the channel, while allowing for drainage during flood events. Because of sea level rise and a net positive deposition of sediment that would occur behind the barrier, the tide gate would need to be raised periodically, but maintenance costs will be minimal. This concept is similar in design to the Thames Flood Barrier (on a much smaller scale), and provides some transient storage. At more advanced levels of sea level rise where gravity flow is lost, provision for pumping stormwater to a point just downstream of I-880 will need to be considered.

7.2. Levee/Floodwall (Damon Slough)

Constructing levees adjacent to either edge of Damon Slough from upstream of I-880 to San Leandro Street can protect adjacent facilities and properties from future high tide levels. Because the footprint of walls, levees and berms would be relatively large, mitigation for loss of habitat and recreation may be required for this strategy. A traditional levee with steeper slopes, or a floodwall with vertical slopes, could be designed and potentially constrained within the existing banks of the slough. This strategy does not include flood protection for I-880. Flooding at I-880 will occur from overland flow from either side of the crossing, in addition to flooding from below in the Damon Slough channel, which is not addressed with this strategy.

7.3. Living Levee (Damon Slough)

Using a combination of natural restoration and aesthetic levees/walls/berms along the length of Damon Slough, the same protection of adjacent assets from flooding can be achieved over using strictly engineered measures. A living levee typically has a flatter waterside slope to allow for the creation of habitat, which results in a wider footprint. A living levee provides additional benefits above flood protection, including increased marsh and riparian habitat which enhances the natural aesthetics of the slough. Because of its larger cross-sectional area, a living levee will also have sufficient accommodation space to allow for future modifications that could support higher rates of sea level rise in the future. However, the footprint of walls, levees and berms would be relatively large, and mitigation for loss of existing habitat and recreation may be required for this strategy. This strategy will also require land acquisition to be effective. This strategy does not include flood protection for I-880, but implementing a wider floodplain in Damon Slough will accommodate higher peak flows and potentially relive some constriction at the I-880 crossing during extreme storm events.

7.4. Fill (Damon Slough)

To prevent high tide overflow in the Coliseum Area and to prevent overtopping of I-880, Damon Slough can be filled to a point just downstream of the I-880 bridges. This would allow the I-880 crossing to be converted to an enclosed culverted battery or similar system that provides adequate drainage from upland flooding. Habitat loss in Damon Slough could be mitigated offsite. Current stormwater runoff entering upstream would need to be diverted to a point just downstream of I-880. Any diversion would need to consider future water levels and its impact on maintaining gravity flow. Where gravity flow is not possible, pumping systems may need to be considered. Maintenance of the drainage system in response to sediment deposition will need to be considered as part of this strategy.

8. POTENTIAL NEXT STEPS

Several next steps can be taken to refine the understanding of the flood dynamics and critical overland flow pathways within this focus area during existing and future conditions. The results from these additional analyses can provide more detail on the level of exposure that assets in this focus area may experience, and may include the following:

- *Update the existing HEC-RAS model* - incorporate the most up to date channel conditions by modeling critical channel structures such as bridges and culverts, and modifying cross section data to include any channel modifications implemented or observed since 2005.
- *Understand the timing of peak flows* - the current steady-state model does not consider the timing of peak flows in the channels. Peak flows occurring at different times can lead to lower flood levels. These processes can be evaluated by incorporating time varying reach boundaries in the HEC-RAS model.
- *Revise the existing DEM* - incorporate new changes in topography from the Airport Connector construction, and other recent channel or floodplain modifications into the existing topographic DEM.
- *Revise the inundation maps* - revise the inundation maps using refined HEC-RAS model output to provide a more detailed assessment of the flooding extents in the focus area.
- *2-dimensional flow modeling* - core assets in low-lying areas are also vulnerable to flooding via overland flow pathways connected to flood sources. These processes may be captured in more detail by using a 2-dimensional flow model (HEC-RAS is 1-dimensional) that can simulate flow through these critical pathways.
- *Evaluate sediment transport* - sea level rise may alter the existing morphology of Damon Slough at the mouth of the channel. Changes include scouring of the channel upstream to the abutments at the I-880 crossing from increased tidal energy. However, these changes will be offset by sediment deposition in the channel from upstream sources. Determining the equilibrium between the two processes as sea levels rise will provide insight to future changes in the morphology of the channel. This can be evaluated by conducting a sediment transport study.

9. REFERENCES

DHI. 2011. *Regional Coastal Hazard Modeling Study for North and Central Bay*. Prepared for FEMA. September.

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Federal Emergency Management Agency (FEMA). 2009. Community Panel Number 06001C0089G, dated 8/3/2009.

San Francisco Bay Conservation and Development Commission, NOAA, Metropolitan Transportation Commission, and California Department of Transportation District 4. 2011. *Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project*. Accessed at http://www.mtc.ca.gov/planning/climate/RisingTides-TechnicalReport.pdf.

Attachment A – Flooding Extents for Selected Scenarios during Existing MHHW Tide Conditions and 24 inches of Sea Level Rise

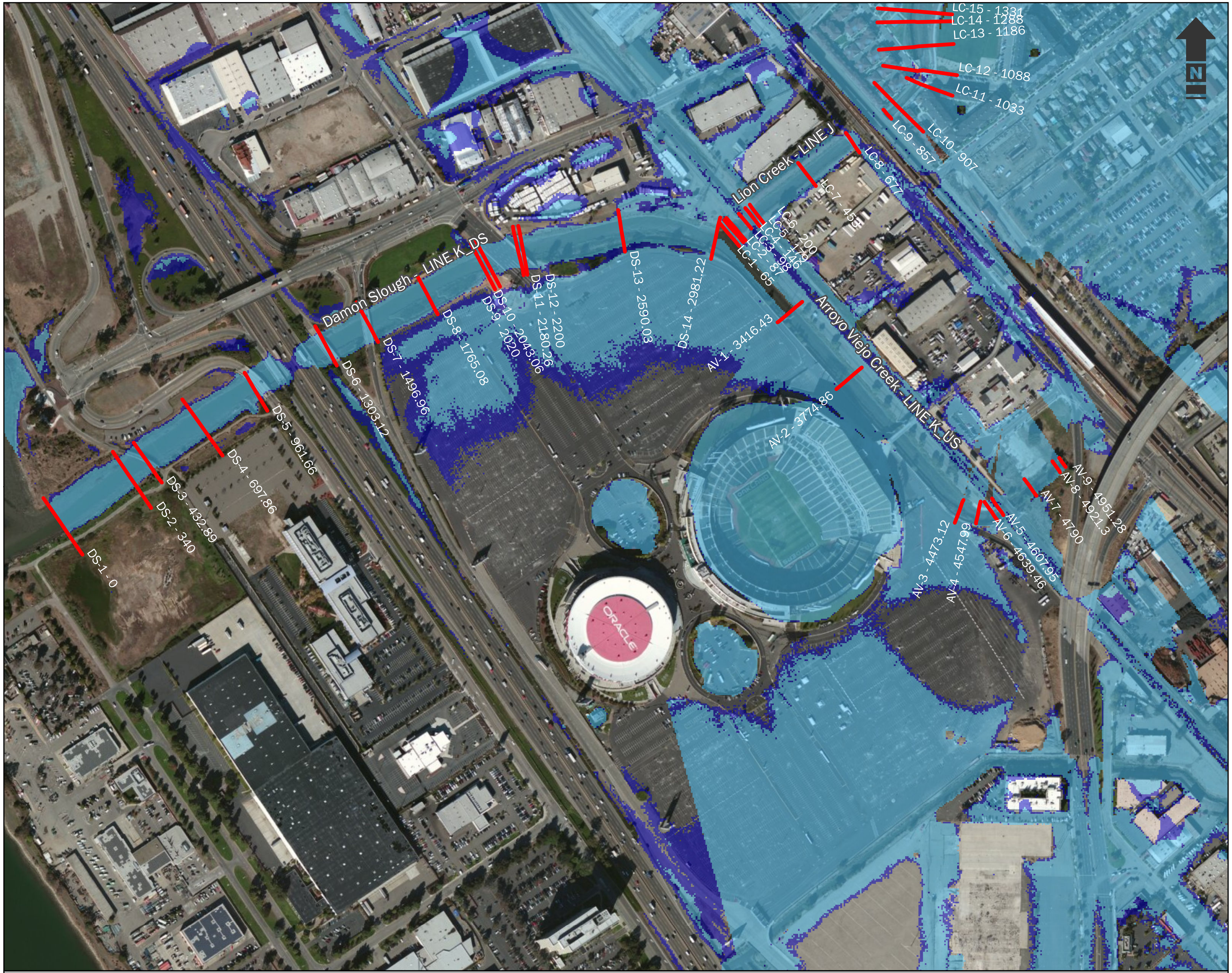
Figure 1 – MHHW + 100-Year Peak Flow (Existing Conditions and 24" SLR)

Figure 2 – 10-Year Extreme Tide Level + 10-Year Peak Flow (Existing Conditions and 24" SLR)

Figure 3 – 10-Year Extreme Tide Level + 100-Year Peak Flow (Existing Conditions and 24" SLR)

Figure 4 – 100-Year Extreme Tide Level + 10-Year Peak Flow (Existing Conditions and 24" SLR)

MTC CLIMATE ADAPTATION
Damon Slough Focus Area
Alameda County



FLOODING EXTENTS

MHHW + 100-YR Peak Flow

MHHW (24" SLR) + 100-YR Peak Flow

HEC-RAS XS

0 250 500 1,000 Feet

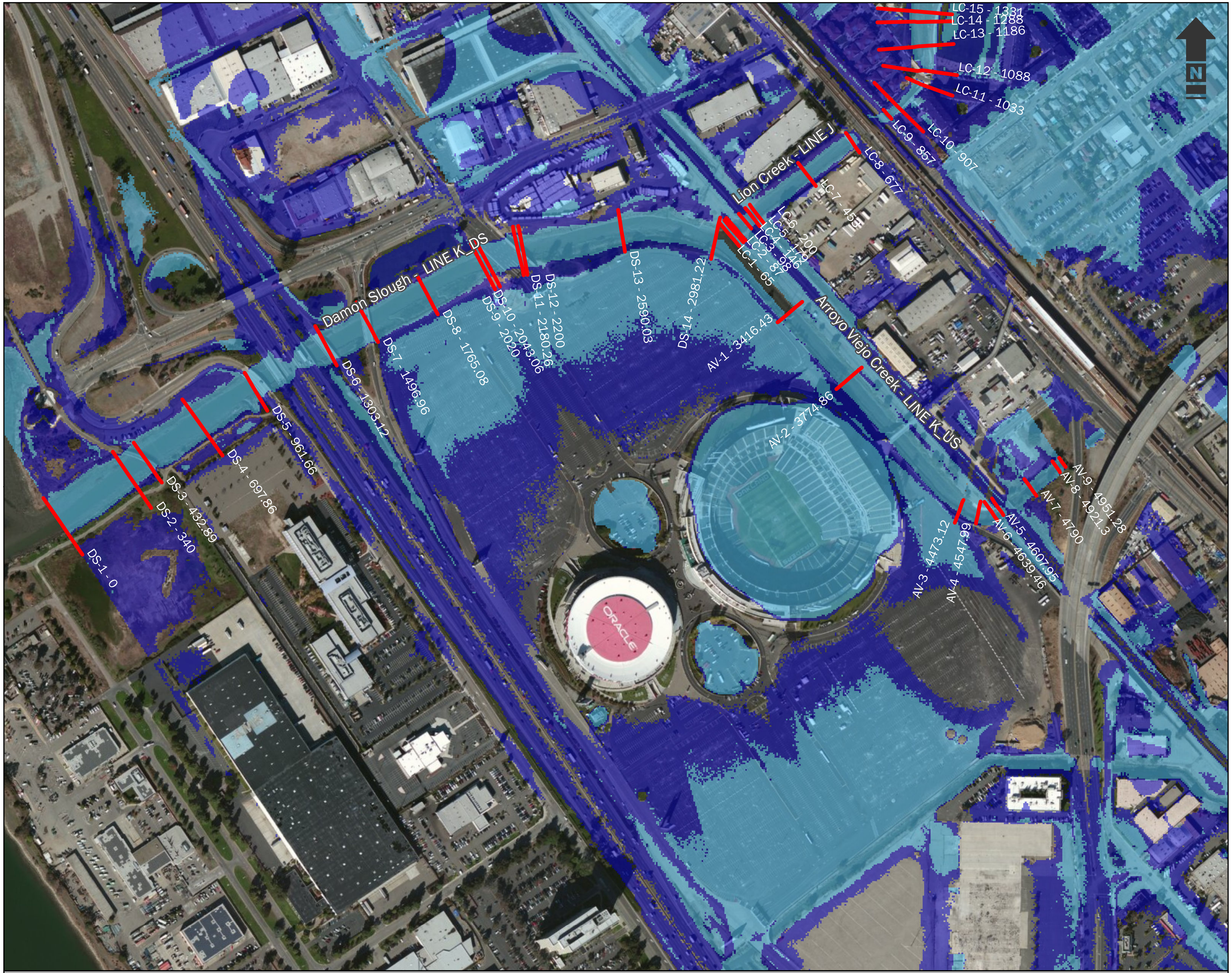
North American Vertical Datum 1988

NAD 1983 StatePlane California III FIPS 0403 Feet

AECOM

4/20/2014

FIGURE 1



MTC CLIMATE ADAPTATION
Damon Slough Focus Area
Alameda County

FLOODING EXTENTS

10-YR Extreme Tide + 10-YR Peak Flow

10-YR Extreme Tide (24" SLR) + 10-YR Peak Flow

HEC-RAS XS

0 250 500 1,000 Feet

North American Vertical Datum 1988

NAD 1983 StatePlane California III FIPS 0403 Feet

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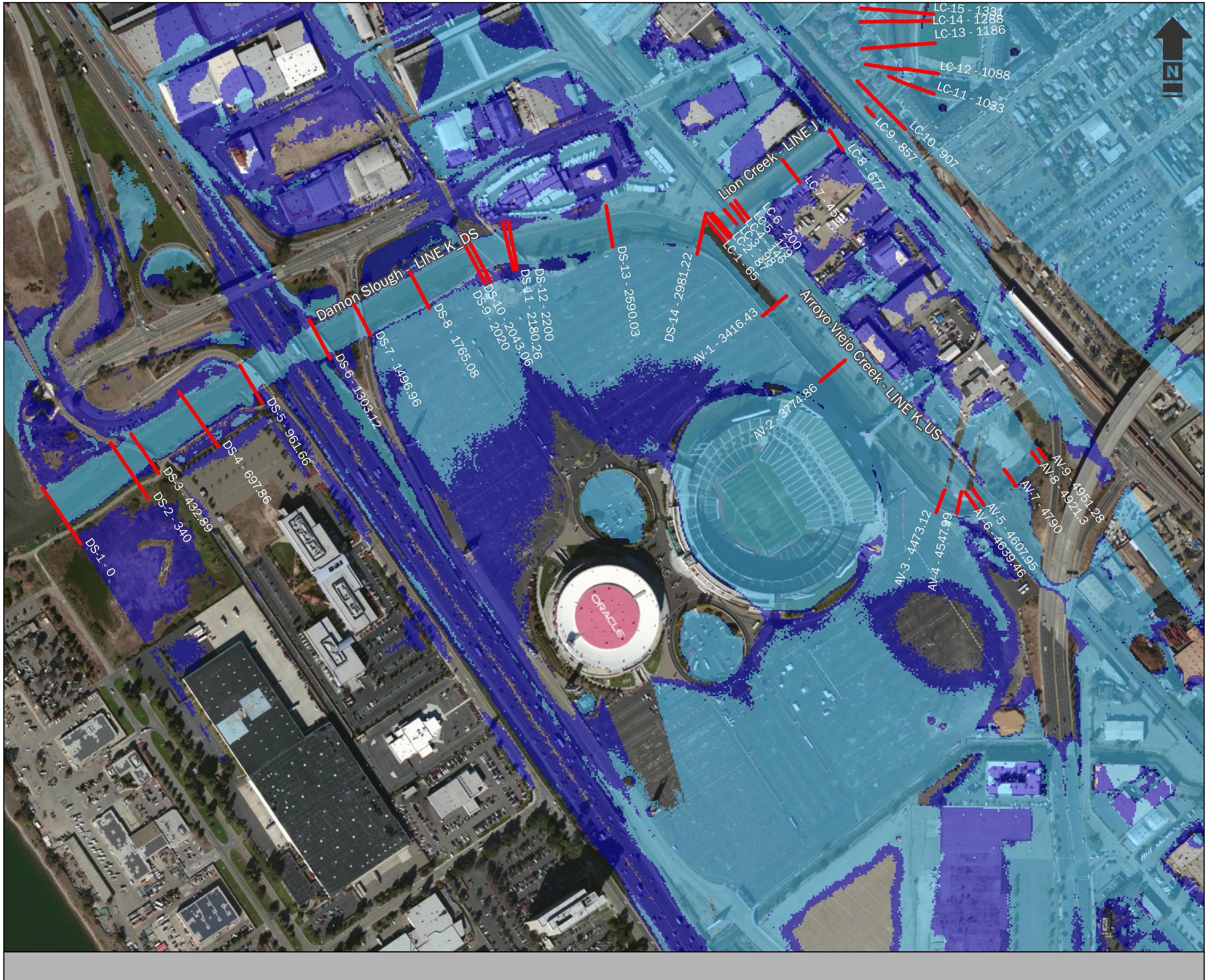
FIGURE 2

MTC CLIMATE ADAPTATION
Damon Slough Focus Area
Alameda County

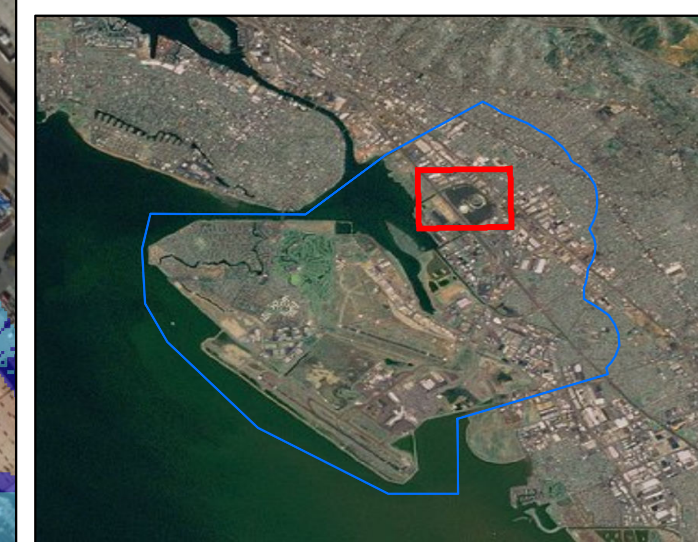


FLOODING EXTENTS

10-YR Extreme Tide + 100-YR Peak Flow

10-YR Extreme Tide (24" SLR) + 100-YR Peak Flow

HEC-RAS XS



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North American Vertical Datum 1988

NAD 1983 StatePlane California III FIPS 0403 Feet

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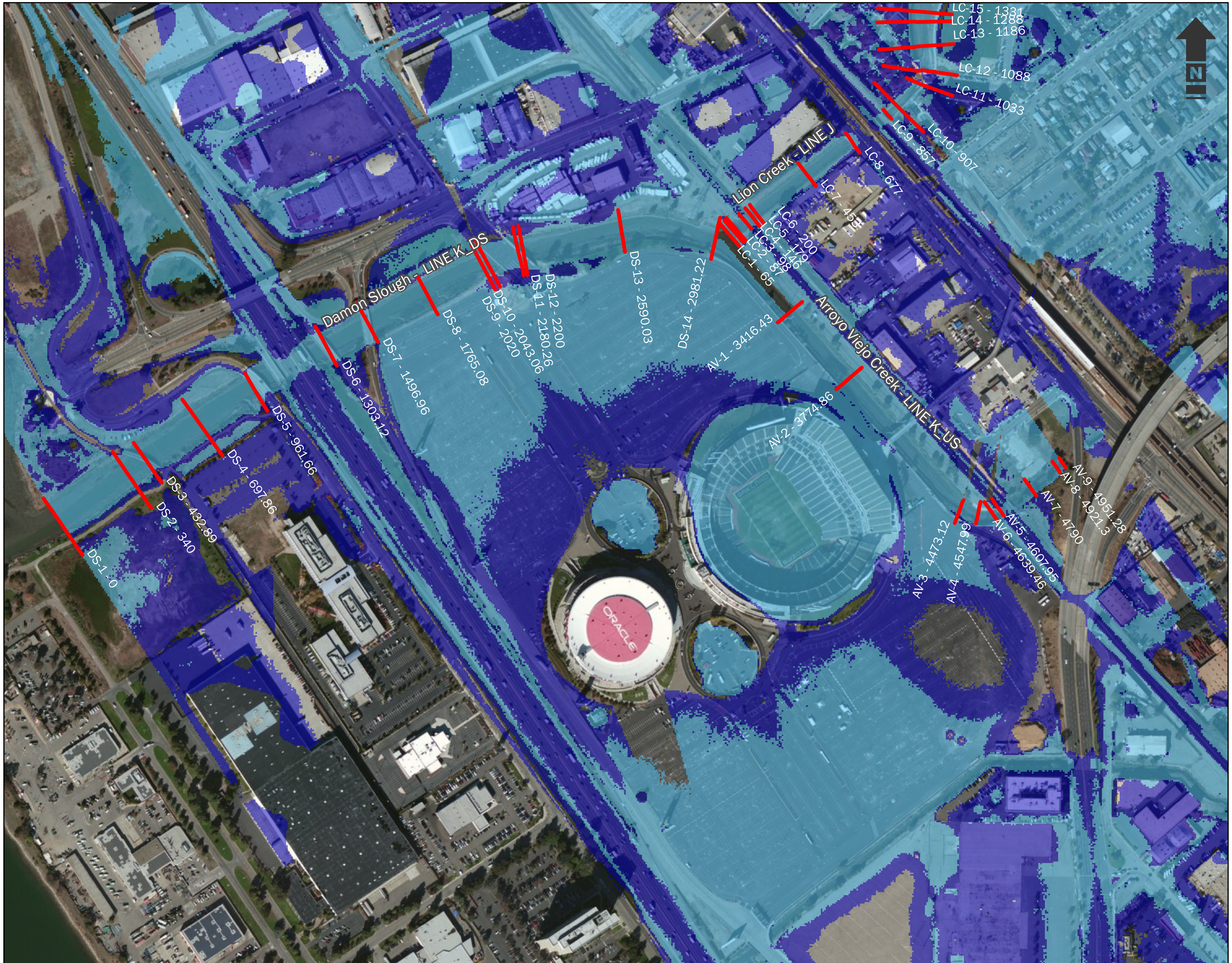
FIGURE 3



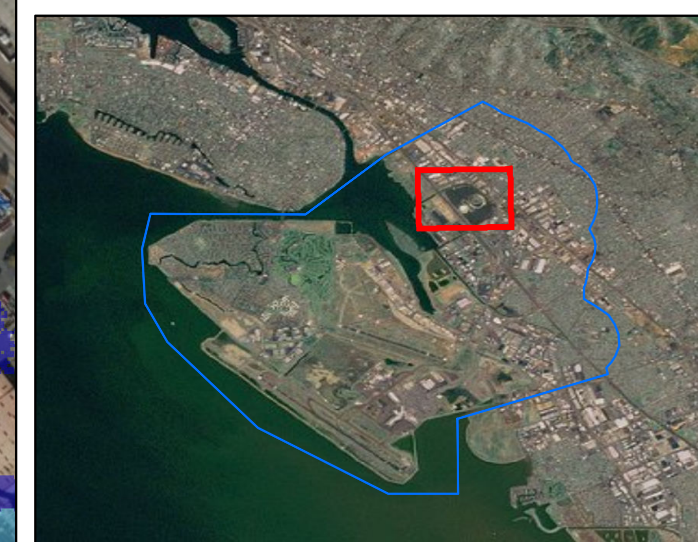
MTC CLIMATE ADAPTATION
Damon Slough Focus Area
Alameda County

FLOODING EXTENTS

100-YR Extreme Tide + 10-YR Peak Flow

100-YR Extreme Tide (24" SLR) + 10-YR Peak Flow

HEC-RAS XS



0 250 500 1,000 Feet

North American Vertical Datum 1988

NAD 1983 StatePlane California III FIPS 0403 Feet

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FIGURE 4

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Memorandum

To	Stefanie Hom (MTC)	Page	1
CC	Wendy Goodfriend (BCDC), Dick Fahey (Caltrans), Norman Wong (BART), Claire Bonham-Carter (AECOM)		
Subject	Hayward Focus Area		
From	Ricky Torres-Cooban, EIT, Michael Mak, P.E., Kris May, Ph.D., P.E.,		
Date	July 1, 2014		

1. INTRODUCTION AND PURPOSE

The Hayward focus area was selected as a focus area for more detailed sea level rise (SLR) exposure analysis and adaptation strategy development as part of the current Metropolitan Transportation Commission (MTC) Climate Adaptation Pilot Study. Under the precursor MTC Vulnerability and Risk Assessment Project (BCDC et al. 2011), this area was shown to be vulnerable to inundation by SLR and coastal storm surge that could impact critical transportation assets and other adjacent assets that support the region, as identified by the Project Management Team (PMT). The purpose of this memorandum is to identify the key areas of vulnerability that exist within the focus area and assess the sources, mechanisms, and timing of inland inundation and flooding to inform the development of adaptation strategies.

This technical memorandum should be considered in tandem with other ongoing work by the San Francisco Bay Conservation and Development Commission (BCDC) and Alameda County Flood Control and Water Conservation District (ACFCWCD) to better understand SLR, storm surge, and shoreline vulnerabilities in Alameda County. The following sections provide a description of the Hayward Focus Area (Section 2), an assessment of exposure to inundation and flooding (Section 3), identification of key areas of vulnerability (Section 4), recommendations for timing of adaptation measures (Section 5), proposed adaptation measures (Section 6) and conclusions (Section 7).

2. FOCUS AREA DESCRIPTION

The Hayward focus area is located between Sulphur Creek and Alameda Creek along the eastern shoreline of San Francisco Bay (Bay) (Figure 1). The focus area includes a significant portion of the Hayward Regional Shoreline and Eden Landing Ecological Reserve as well as the San Mateo-Hayward Bridge touchdown. The shoreline of this focus area is comprised of a complex of fully tidal, muted tidal, and managed marshes and ponds. Bayfront and internal non-engineered berms separate the marshes, ponds, former oxidation ponds, and inland developed areas from direct exposure to the Bay (except for Cogswell Marsh and South Eden Landing Ecological Reserve, which have a natural marsh edge). This system of structural and natural shorelines acts as a buffer that reduces the risk of coastal flood hazard impacts on inland developments. The non-engineered berms were created from

Bay mud and fill, and although these structures are not certified or accredited flood protection structures[1], they do provide some level of flood protection and reduce wave hazards as they reach inland areas. Some of the berms also have integrated recreational trails that are part of the San Francisco Bay Trail system. The inland areas protected by the shoreline are primarily industrial land uses, with some small areas of residential and commercial uses. As shown on Figure 1, important assets in this focus area in addition to the San Mateo-Hayward Bridge touchdown include California State Route (SR) 92 (Area A), the Hayward Shoreline Interpretive Center, the Old West Winton Landfills (near Area B), and the City of Hayward Water Pollution Control Facility (Area H).

The fully tidal and muted tidal marshes experience regular tidal inundation under existing conditions. Managed marshes and ponds in the focus area have been engineered with water control structures (e.g., culverts, weirs, and tide gates) to control tidal flow. For the Hayward Marsh, which receives secondarily treated wastewater from Union Sanitary District, the water control structures assist in improving water quality prior to discharge to the Bay. Most of the shoreline in the focus area is protected to some degree by engineered protection (rock and rubble) except, most notably, in the southern extent of the focus area within the Eden Landing Ecological Reserve and in the northern extent along Cogswell Marsh.

The AECOM team performed a site visit on May 17, 2014. Visual inspection of shoreline protection structures, tide control structures, and assets was performed along the shoreline north of the San Mateo Bridge touchdown. See Attachment A for site visit photos.

[1] Flood protection structures can be certified by the United States Army Corps of Engineers and/or accredited by the Federal Emergency Management Agency for providing protection from the 100-year (1% annual chance) flood event

AECOM

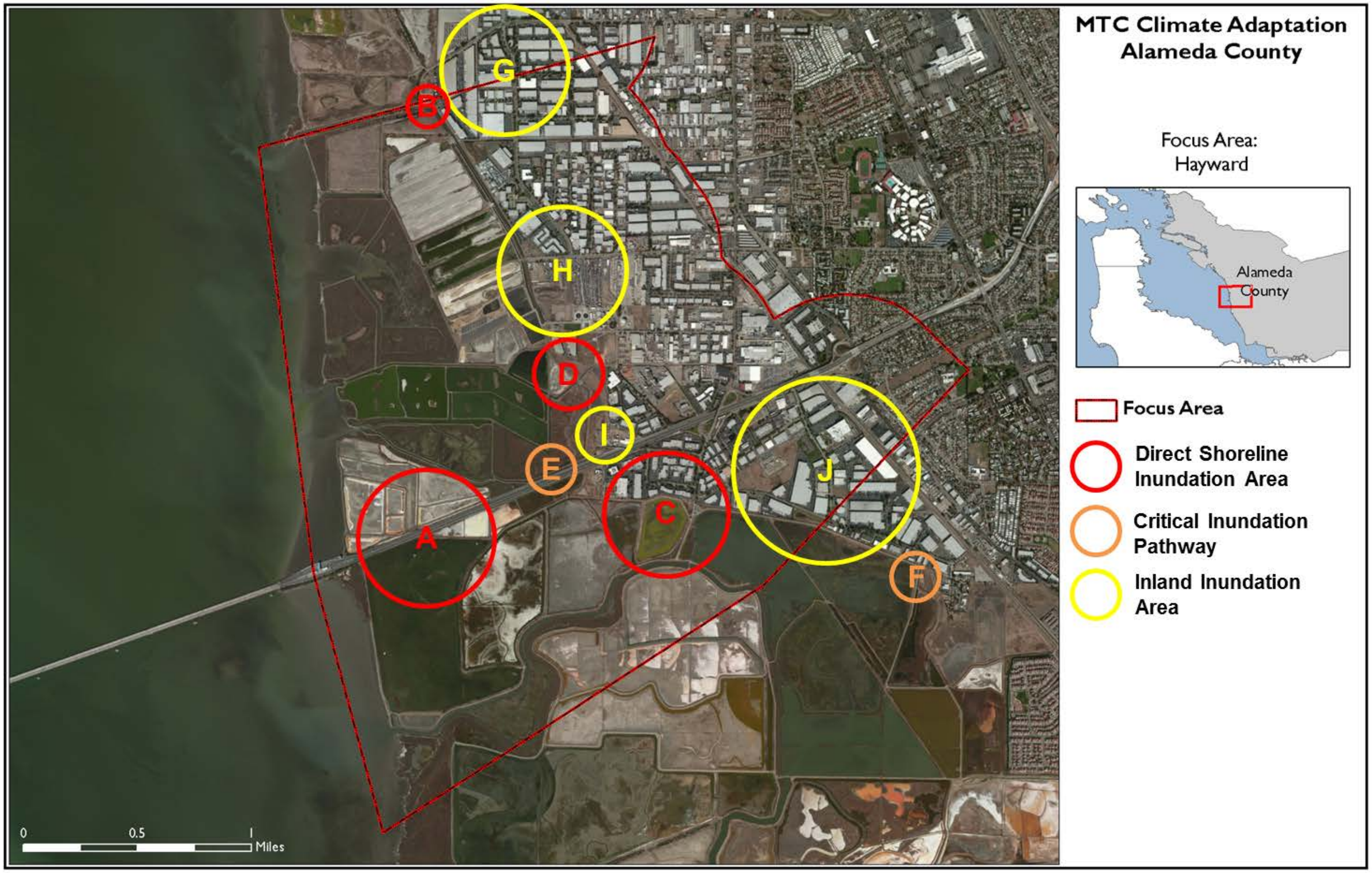

Figure 1. Hayward Focus Area Site Location Map and Inundation Areas

Note: Circles are used to indicate approximate locations and extents of inundation. Circle sizes do not correspond to intensity, timing, or risk of inundation.

3. INUNDATION AND FLOODING EXPOSURE

In the discussion that follows, a clear distinction is made between the terms *inundation* and *flooding*. Permanent *inundation* occurs when an area is exposed to regular daily tidal inundation. A permanently inundated area can no longer be used in the same way as an inland area due to the frequency of its exposure to sea water. In contrast, *flooding* occurs when an area is exposed to episodic, short duration, extreme tide events of greater magnitude than normal tide levels. Inland areas may be temporarily flooded during an extreme tidal event while maintaining at least a portion of their functionality once the floodwaters recede. However, sensitive assets may suffer irreversible damage if exposed to any amount of water, even temporarily. The term flooding, as it is used throughout this memorandum, is therefore a temporary inundation condition that results from a storm event rather than the permanent inundation due to daily high tides.

To assess portions of the shoreline that are exposed to inundation and flooding within the Hayward focus area, six sea level rise and inundation mapping scenarios were examined (Table 1). Inundation maps were created for each of the scenarios using the methodology developed by the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (Marcy et al. 2011). The scenarios were developed by adding different amounts of SLR onto the elevation of the existing conditions daily high tide level (represented by the Mean Higher High Water (MHHW) tide). The MHHW reference water levels used in this analysis were derived from MIKE21 model output from a regional San Francisco Bay modeling study completed as part of the Federal Emergency Management Agency (FEMA) San Francisco Bay Area Coastal Study [2] (DHI 2011). The modeling study spanned a 31-year period from January 1, 1973 to December 31, 2003. The MHHW tidal datum was calculated using the portion of the model output time series corresponding to the most recent National Tidal Datum Epoch (1983 through 2001), which is a specific 19-year period adopted by NOAA to compute tidal datums.

In accordance with the most up-to-date SLR projections from the National Research Council (NRC, 2012), the following scenarios were evaluated for the present study: 12-inch, 24-inch, 36-inch, and 48-inch above MHHW. In addition to these scenarios, 72-inch and 96-inch above MHHW were also evaluated, but these water levels are outside the range of current scientific predictions for SLR and, therefore, do not correspond with permanent inundation scenarios that are likely to occur before 2100 (NRC, 2012). These scenarios are included to evaluate important extreme flooding scenarios that could happen during storm surge events with lesser amounts of SLR. In general, though, the mapped scenarios can occur due to SLR, storm surge, or a combination of the two.

Mapped scenarios are listed in Table 1**.** The inundation maps for this focus area were developed by AECOM as a part of the Alameda County Sea Level Rise Shoreline Vulnerability Assessment for BCDC and ACFCWCD and are shown in Attachment B. The maps show inundation areas and depths as well as overtopping potential lines along the shoreline and the edges of the highway. “Overtopping potential” refers to the condition where the water surface elevation associated with a particular reference water level exceeds the elevation of the shoreline asset. The depth of overtopping potential at each shoreline segment is calculated by taking an average of several depths over the length of the segment.

[2] www.r9coastal.org

This assessment is considered a planning-level tool only, as it has some limitations. It does not account for the physics of wave runup 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 complex sediment transport processes of the managed marshes and ponds, in addition to the flow that may occur through the water control structures, are not included in this assessment. Marshes and ponds are assumed to maintain the elevations captured by the digital elevation model (DEM)[3], neglecting possible deposition or erosion that is likely to take place.

Table 1. Sea Level Rise Inundation Mapping Scenarios

Mapping Scenario	Reference Water Level	Applicable Range for Mapping Scenario (Reference +/- 3 inches)
Scenario 1	MHHW + 12-inch	MHHW + 9 – 15 inch
Scenario 2	MHHW + 24-inch	MHHW + 21 – 27 inch
Scenario 3	MHHW + 36-inch	MHHW + 33 – 39 inch
Scenario 4	MHHW + 48-inch	MHHW + 45 – 51 inch
Scenario 5	MHHW + 72-inch	MHHW + 69 – 75 inch
Scenario 6	MHHW + 96-inch	MHHW + 93 – 99 inch

It is important to understand that the reference water levels listed for each mapping scenario can occur due to a variety of hydrodynamic conditions by combining different amounts of SLR with either a daily[4] or extreme high tide. For example, Scenario 3 (MHHW + 36-inch) represents both a daily high tide with 36 inches of SLR or a 50-year extreme tide with no sea level rise (i.e., existing conditions). A +/- 3 inch tolerance was added to each reference water level to increase the applicable range of the mapped scenarios. For example, Scenario 3 (MHHW + 36-inch) is assumed to be representative of all extreme tide/SLR combinations that produce a water level in the range of MHHW + 33 inches to MHHW + 39 inches. By combining different amounts of SLR and extreme tide levels, a matrix of water level scenarios was developed to identify the various combinations represented by each inundation map.

The matrix of SLR and tide scenarios is presented in Table 2. Values are in shown in inches above the existing conditions MHHW tidal level. The colors shown in Table 2 match the colors shown in Table 1. The colors indicate the different combinations of SLR and extreme tide scenarios represented by each inundation map. Note that Scenarios 5 and 6 correspond only to extreme tide

[3] A 2-meter digital elevation model (DEM) was developed from the 2010 LiDAR data collected by the United States Geological Survey (USGS) and National Oceanic Atmospheric Administration (NOAA) as part of the California Coastal Mapping Program (CCMP)

[4] Mean Higher High Water (MHHW) is used as a surrogate for the average daily high tide. MHHW is the average of the higher high water level of each tidal day observed over the National Tidal Datum Epoch. It should be noted that. The actual higher high tide that occurs on any given day will be higher or lower than MHHW. MHHW is approximately 7.0 ft NAVD88 within this focus area.

events as they are outside of the range of projections for probable SLR over the next century. The first row of the table shows values for existing conditions. For example, to read Table 2, the inundation map that represents MHHW + 36-inch (Scenario 3), would also represent a 1-yr event with 24 inches of SLR, a 2-yr event with 18 inches of SLR, a 5-yr event with 12 inches of SLR, etc. Equivalent water levels for the MHHW + 12-inch, MHHW + 24-inch, MHHW + 36-inch, MHHW + 48-inch, MHHW + 72-inch, and MHHW + 96-inch mapping scenarios can be determined similarly by tracking the color coding through the table. To reinforce these relationships, "X-inch scenario" and "MHHW + X-inch" will be used throughout this memorandum to refer to specific inundation maps and mapped scenarios (e.g., "48-inch scenario" or "MHHW + 48-inch" instead of "48 inches of SLR") since the scenario can be associated with multiple combinations of sea level rise and extreme tide events. Table 2 can also be used to plan for a particular level of risk. For example, to examine infrastructure exposure to a 100-yr extreme tide event with an estimated 6 inches of SLR, the MHHW + 48-inch mapping scenario could be examined. Using this approach, it is possible to assess flood risk to assets at various time scales and frequency of flooding.

Table 2. Matrix of Water Levels Associated with Sea Level Rise and Extreme Tide Scenarios

	Daily Tide	Extreme Tide (Storm Surge)						
Sea Level Rise Scenario	Water Level above MHHW	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Existing Conditions	0	15	20	24	27	32	36	41
MHHW + 6-inch	6	21	26	30	33	38	42	47
MHHW + 12-inch	12	27	32	36	39	44	48	53
MHHW + 18-inch	18	33	38	42	45	50	54	59
MHHW + 24-inch	24	39	44	48	51	56	60	65
MHHW + 30-inch	30	45	50	54	57	62	66	71
MHHW + 36-inch	36	51	56	60	63	68	72	77
MHHW + 42-inch	42	57	62	66	69	74	78	83
MHHW + 48-inch	48	63	68	72	75	80	84	89
MHHW + 54-inch	54	69	74	78	81	86	90	95
MHHW + 60-inch	60	75	80	84	87	92	96	101

Note: All values in inches above existing conditions MHHW at Hayward Focus Area. The extreme tide levels above MHHW were derived from the FEMA MIKE 21 model output. Color coding indicates which combinations of sea level rise and extreme tides are represented by the mapping scenarios shown in Table 1. Cells with no color coding do not directly correspond to any of the mapping scenarios shown in Table 1.

4. KEY FOCUS AREA RESULTS

By combining the information available in the water level matrix (Table 2) with the results of the inundation mapping and overtopping potential calculations, shoreline exposure to inundation/flooding and the timing of exposure can be evaluated. Floodwaters must first overtop the system of bayfront and internal berms before reaching the vast majority of inland development in this focus area. Since the marshes and ponds within the focus area are regularly inundated to some extent by tidal waters, the effects of temporary inundation are not likely to be significant with the exception of vegetation loss and drowning if floodwaters linger for extended periods and possible degradation of the overtopped berms and water control structures. As sea levels rise, this progressively overtopped shoreline system becomes an interconnected network of drowned marshes and ponds that can inundate adjacent areas at various thresholds. These thresholds are identified in Section 4.1. In some areas, successive internal berms need to be overtopped in order for storm surge events to have an impact. Estimating realistic flood volumes due to overtopping is not practical given the current level of information readily available; thus, the extent of temporary flooding depicted on the inundation maps, particularly when overtopping of successive internal berms occurs, may be overestimated. In addition, the water control structures that connect many of the ponds and adjacent areas are not considered in this analysis; these structures can both enhance and inhibit hydraulic connectivity. Topographic elevations within in the marshes and ponds may change significantly over time due to accumulation of organic matter and sediment transport processes, as mentioned in Section 3. These processes are not simulated as a part of this assessment and all topographic elevations are assumed to remain stationary.

In addition to conducting an evaluation of flood processes occurring within this system, this study identified ten key areas of vulnerability within the Hayward focus area based on a detailed review of the inundation mapping. Timing of inundation and proximity to important assets were the fundamental criteria used to select these areas, which are identified in Figure 1 and Figure 2 and labeled letters "A" through "J." These areas can be grouped into three categories—*shoreline inundation areas*, *critical inundation pathways*, and *inland inundation areas*. In both figures, shoreline inundation hazard areas are labeled in red (A-D), critical inundation pathways in orange (E-F), and inland inundation areas in yellow (G-J). Figure 2 below also shows a general overview of the sources of flooding and the pathways that allow floodwaters to progress inland.

Shoreline inundation areas are immediately adjacent to the shoreline and are both the most vulnerable to flooding and the most likely to experience permanent inundation as a result of SLR. These areas are where the shoreline is first overtopped and from which floodwaters propagate to areas immediately inland. Four shoreline inundation areas were identified for the Hayward focus area.

Inland inundation areas are not directly adjacent to the shoreline and require a hydraulic pathway to convey flood waters from the Bay to the inland area. These areas are the least likely to experience the full extent of temporary flooding depicted in the inundation maps due to the typical duration of a coastal storm surge event and the volume of water that would be required to fill these expansive low-lying areas during an episodic event. To determine the exact extent of inland flooding or permanent inundation, more sophisticated modeling is required; however, the exposure of these areas to potential inundation and flooding is well represented by the inundation maps for the purposes of this study. Four inland inundation areas were identified within the Hayward focus area.

Critical inundation pathways connect shoreline inundation areas to the inland inundation areas, providing the necessary hydraulic connectivity to convey flood waters to inland areas. Two critical inundation pathways were identified within the Hayward focus area.

To facilitate understanding, the Hayward focus area has been subdivided into three regions based on the flooding patterns within the focus area that occur with less than 36 inches of sea level rise (Figure 2): the area North of SR 92 (North); the area at and adjacent to SR 92 (SR 92); and the area South of SR 92 (South). Results for areas north of SR 92 are presented in Section 4.2; results for areas immediately adjacent to SR 92 are presented in Section 4.3; and results for areas south of SR 92 are presented in Section 4.4.

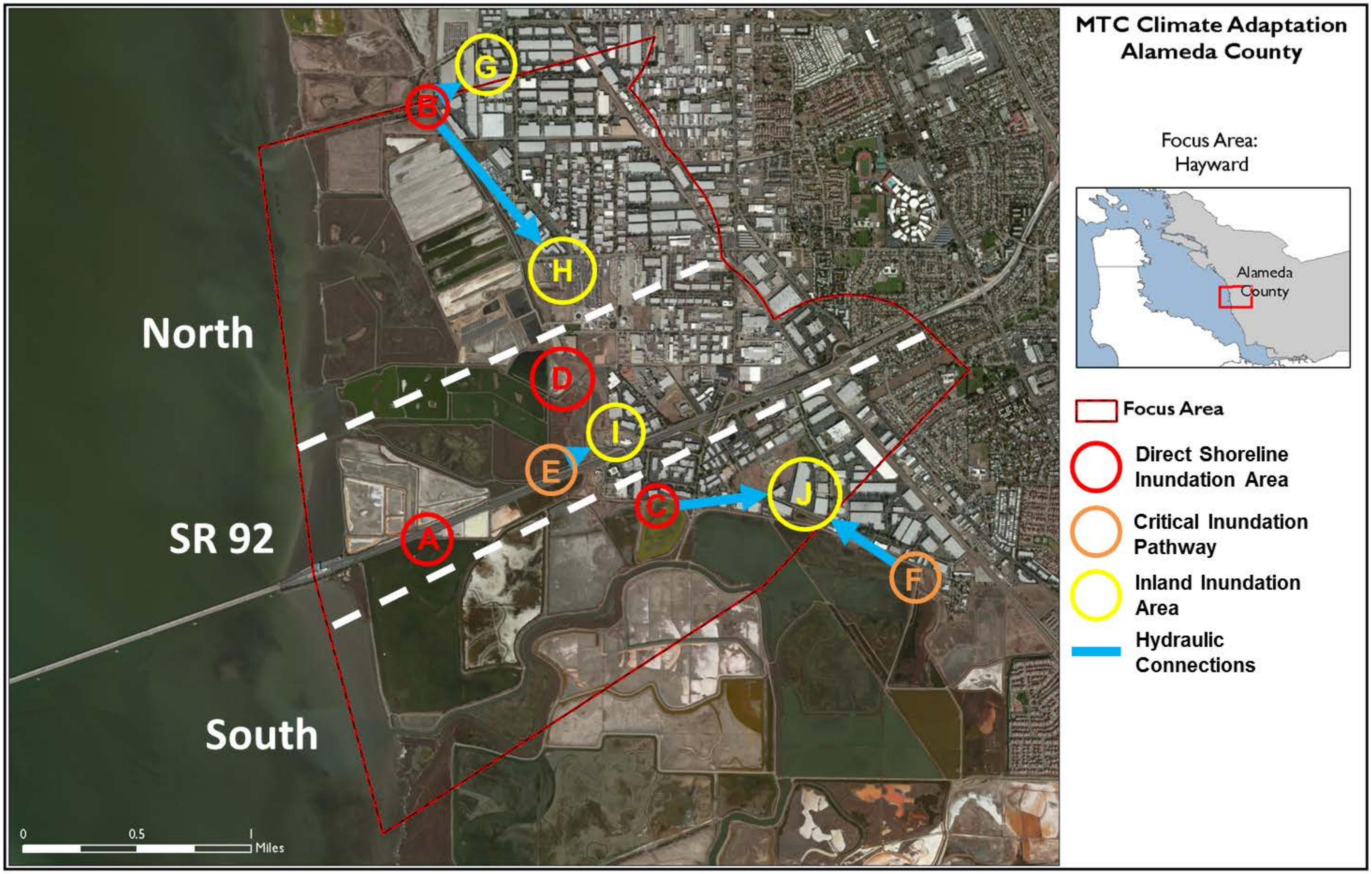

Figure 2. Delineation of Inundation Regions and Connections between Inundation Areas

4.1 MANAGED MARSHES AND PONDS

There are eight distinct marsh areas or ponds within the Hayward focus area, and these areas are typically separated by the network of internal and bayfront berms (Figure 3). The majority of this system is part of the Hayward Regional Shoreline, with the exception of Eden Landing Ecological Reserve, which is part of the Eden Landing system owned by the California Department of Fish and Wildlife. Figure 3 shows the timing of inundation throughout the system and the critical segments that will be overtopped, thereby inundating the adjacent area(s). Triangle Marsh, Cogswell Marsh, HARD Marsh and Eden Landing Ecological Reserve are directly connected to the Bay by natural and/or engineered inlets and are actively flooded under existing conditions. As expected, these areas are inundated in the 12-inch scenario[5]. In the 24-inch scenario, the internal berms surrounding HARD Marsh are overtopped and inundate the Salt Marsh Harvest Mouse Preserve and Oliver Salt Ponds. In the 36-inch scenario, the berm between Hayward Marsh and HARD Marsh is overtopped as well as the berm between Cogswell Marsh and the Oxidation Ponds. All internal berms are overtopped in the 72-inch scenario (which results in a level of inundation that could occur with 30 inches of SLR and a 100-year storm surge event, as shown in Table 2) and the entire system is inundated. The eight inundation areas are summarized below:

- Triangle Marsh (Figure 3)
  - Inundation first occurs at the 12-inch scenario with inundation depths of 0-6 feet
  - Fully tidal under existing conditions
- Cogswell Marsh (Figure 3)
  - Inundation first occurs at the 12-inch scenario with inundation depths of 0-6 feet
  - Fully tidal under existing conditions
- Hayward Marsh (Figure 3)
  - Inundation first occurs at the 36-inch scenario with inundation depths of 0-3 feet
- HARD Marsh (Figure 3)
  - Inundation first occurs at the 12-inch scenario with inundation depths of 0-6 feet
  - Fully tidal under existing conditions
- Oliver Salt Ponds (Figure 3)
  - Inundation first occurs at the 24-inch scenario with inundation depths of 0-6 feet
- Oxidation Ponds (Figure 3)
  - Inundation first occurs in the south at the 36-inch scenario with inundation depths of 0-9 feet
  - The entire area is inundated at the 48-inch scenario with inundation depths of 0-9 feet
- Salt Marsh Harvest Mouse Preserve (Figure 3)
  - Inundation first occurs at the 24-inch scenario with inundation depths of 0-6 feet

[5] The sea level rise scenario when the site is first overtopped has been approximated based on the mapped sea level rise inundation scenarios (e.g., 12", 24", 36", 48"). The actual sea level rise scenario which results in overtopping may be less than this amount (i.e., if the sea level rise scenario of first overtopping is 36 inches, overtopping is first observed in this mapped scenario, but overtopping may occur as early as 25 inches). Refined shoreline tools have been developed for this area that can estimate the overtopping threshold within 6 inch increments, and these tools can be used for future updates to this assessment.

- Eden Landing Ecological Reserve (Figure 3)
  - Partial inundation first occurs at the 12-inch scenario with inundation depths of 0-3 feet
  - The entire area is inundated at the 24-inch scenario with inundation depths of 0-9 feet

4.2 NORTH OF SR 92

North of SR 92, the primary sources of inundation are from natural and engineered flood control channels that are overtopped (Figure 4). One shoreline inundation area (Area B) was identified in this region as well as two inland inundation areas (Areas G and H). Shoreline inundation areas are presented in Section 4.2.1 and inland inundation areas are presented in Section 4.2.2.

4.2.1 SHORELINE INUNDATION AREAS

One shoreline inundation area (Area B) was identified in the region north of SR 92. Overtopping of Zone 4 Line A flood control channel near the intersection of W Winton Avenue and Depot Road first occurs at the 36-inch scenario and results in the exposure of inland assets located in Area G, as summarized below:

- Area B (Figure 4)
  - Overtopping of the engineered flood control channels east of Triangle Marsh first occurs at the 36-inch scenario with inundation depths of 0-3 feet
  - W Winton Avenue is partially inundated from areas to the north and from overtopping of the flood control channel to the south
  - Industrial buildings and parking lots are partially inundated (Area G)

4.2.2 INLAND INUNDATION AREAS

Two inland inundation areas (Areas G and H) were identified in the region north of SR 92. Both are inundated as a result of overtopped natural and engineered channels. Area G is inundated first at the 36-inch scenario due to overtopping at Area B. Area H is inundated at the 48-inch scenario when the flood control channel east of the former oxidation ponds is overtopped at several places near Depot Road. A summary of the inland inundation areas for this region is included below:

- Area G (Figure 4)
  - Mostly industrial and parking areas
  - Inundation first occurs at the 36-inch scenario with depths of 0-3 feet
  - Source of flooding is overtopped channels at Area B

- Area H (Figure 4)
  - Mostly industrial and parking areas
  - Inundation first occurs at the 48-inch scenario with depths of 0-3 feet
  - Source of flooding is overtopped natural and flood control channels east of the oxidation ponds
  - City of Hayward Water Pollution Control Facility is partially flooded at the 72-inch scenario with depths of 0-3 feet

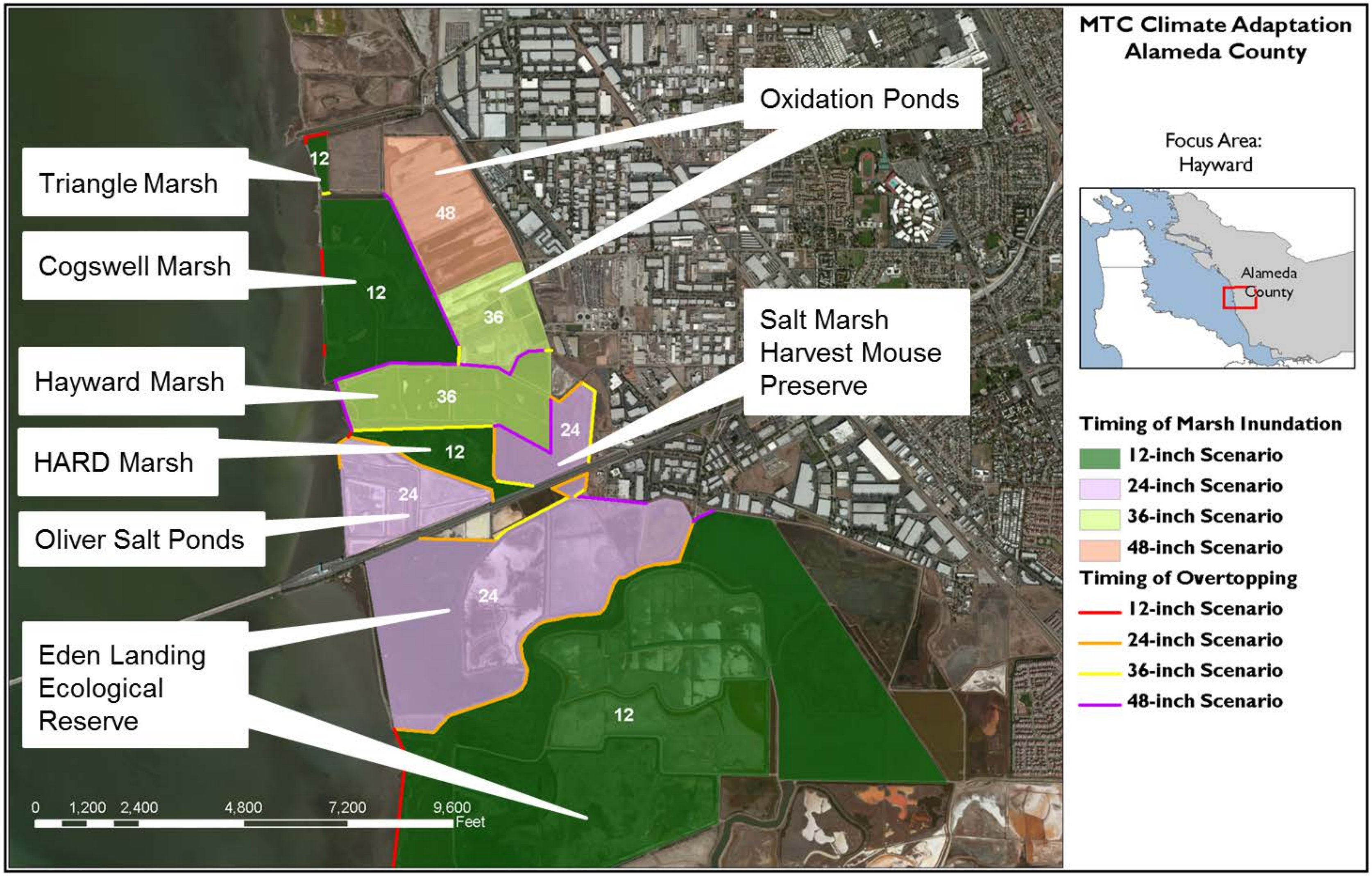

Figure 3. Timing of Bayfront Inundation and Locations of Overtopping at Non-Engineered Berms.
Note: Numbers denote the first sea level rise scenario that results in inundation (in inches above MHHW).

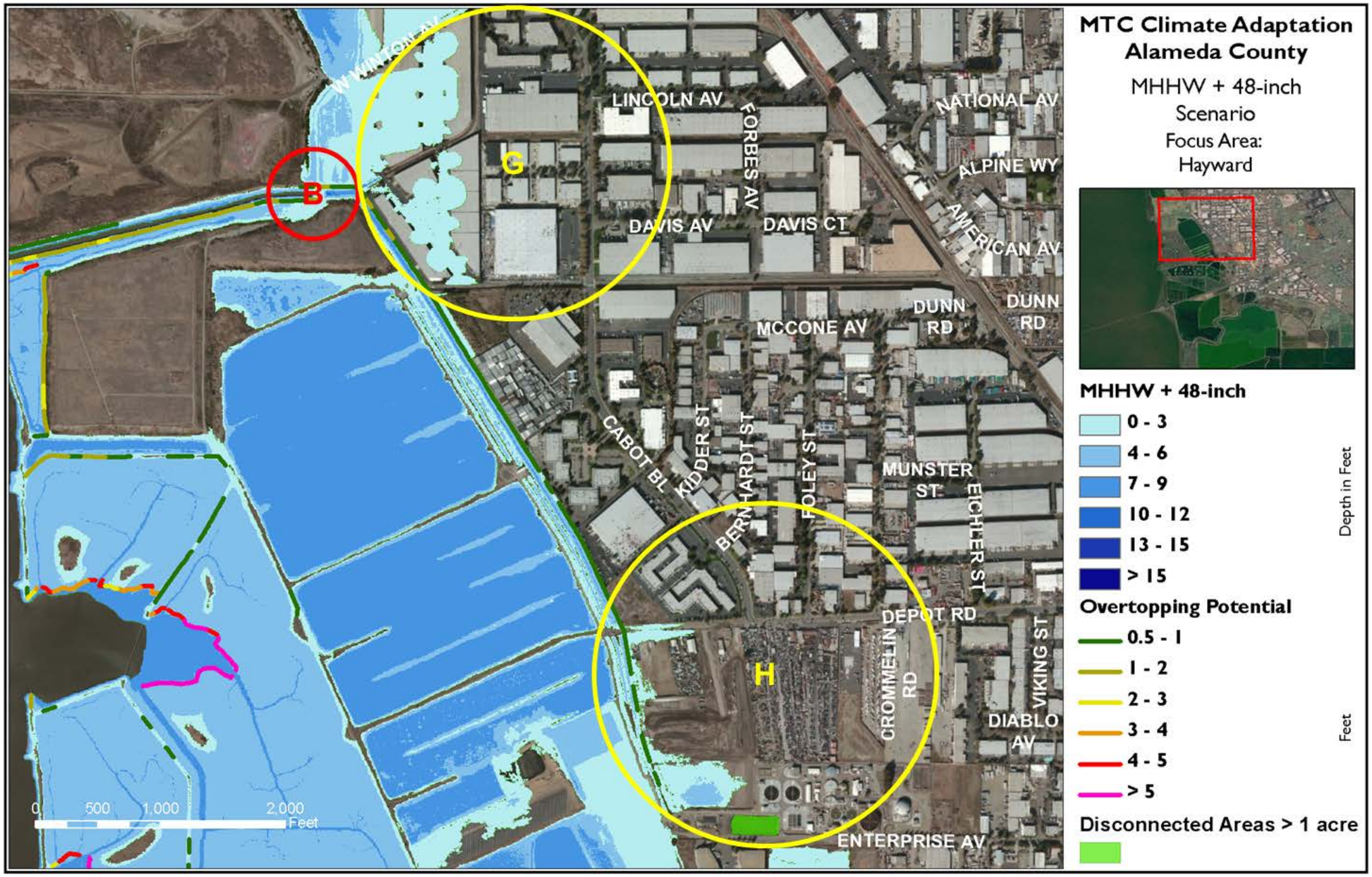

Figure 4. Inundation Areas North of SR 92 (MHHW + 48-inch Scenario)

4.3 SR 92

Inundation of SR 92 and adjacent areas occurs primarily from overtopping of non-engineered berms along Oliver Salt Ponds, HARD Marsh, and Salt Marsh Harvest Mouse Preserve (Figure 5 and Figure 6). Two shoreline inundation areas (Areas A and D) were identified in this region. Additionally, a critical inundation pathway (Area E) results in inundation of inland areas (Area I). Shoreline inundation areas within this region are discussed in Section 4.3.1; critical inundation pathways in this region are discussed in Section 4.3.2; and inland inundation areas within this region are discussed in Section 4.3.3.

4.3.1 SHORELINE INUNDATION AREAS

Two shoreline inundation areas (Areas A and D) were identified at SR 92. First, inundation and overtopping of HARD Marsh and the Salt Marsh Harvest Mouse Preserve at the 24-inch scenario results in limited shoreline inundation that reaches the antenna towers near Enterprise Avenue and several industrial buildings and parking areas near Johnson Road (Area D). Partial inundation of Breakwater Avenue, adjacent to SR 92, occurs at the 36-inch scenario (Area A). At the 48-inch scenario, Breakwater Avenue is completely inundated and significant areas on SR 92 are also inundated. A summary of the shoreline inundation areas is presented below:

- Area A (Figure 5)
  - ➢ Partial inundation of Breakwater Avenue first occurs at the 36-inch scenario with inundation depths of 0-3 feet
  - ➢ Partial inundation of the outermost highway lanes south of the Oliver Salt Ponds first occurs at the 48-inch scenario with inundation depths of 0-3 feet

- Area D (Figure 6)
  - ➢ Overtopping of the non-engineered berm in the north of Salt Marsh Harvest Mouse Preserve first occurs at the 24-inch scenario with inundation depths of 0-3 feet
  - ➢ Antenna towers near Enterprise Avenue are partially inundated

4.3.2 CRITICAL INUNDATION PATHWAYS

One critical inundation pathway (Area E) was identified at SR 92. It is first overtopped at the 24-inch scenario (Figure 6). A single controlling feature was confirmed at the landward terminus of the channel along Breakwater Avenue at the Salt Marsh Harvest Mouse Preserve that results in extensive inland inundation of adjacent areas when overtopped. The high point of the critical inundation pathway occurs at an elevation of approximately 8 feet NAVD88. Figure 7 shows a representative transect of the elevation profile along Area E starting in the channel and extending inland over the non-engineered berm. The MHHW + 24-inch water level is shown for reference relative to the topography. Key observations for the critical inundation pathway are summarized below:

- Area E (Figure 6; Figure 7)
  - Narrow channel along Breakwater Avenue is inundated, overtopped at the southeast corner of Salt Marsh Harvest Mouse Preserve and connects the flooding from HARD Marsh to inland Area I
  - First occurs at the 24-inch scenario with inundation depths of 0-3 feet
  - Immediately east of Hayward Shoreline Interpretive Center
  - Critical water level of approximately 8 feet NAVD88

4.3.3 INLAND INUNDATION AREAS

One inland inundation area (Area I) was identified at SR 92. Exposure occurs when the critical inundation pathway Area E is overtopped at the 24-inch scenario (Figure 6). More extensive flooding occurs at the 36-inch scenario when the non-engineered berm that forms the eastern boundary of Salt Marsh Harvest Mouse Preserve is overtopped almost entirely. A summary of the inland inundation areas is presented below:

- Area I (Figure 6)
  - Mostly industrial and parking areas
  - Inundation first occurs at the 24-inch scenario with depths of 0-3 feet
    Source of flooding is HARD Marsh via Area E

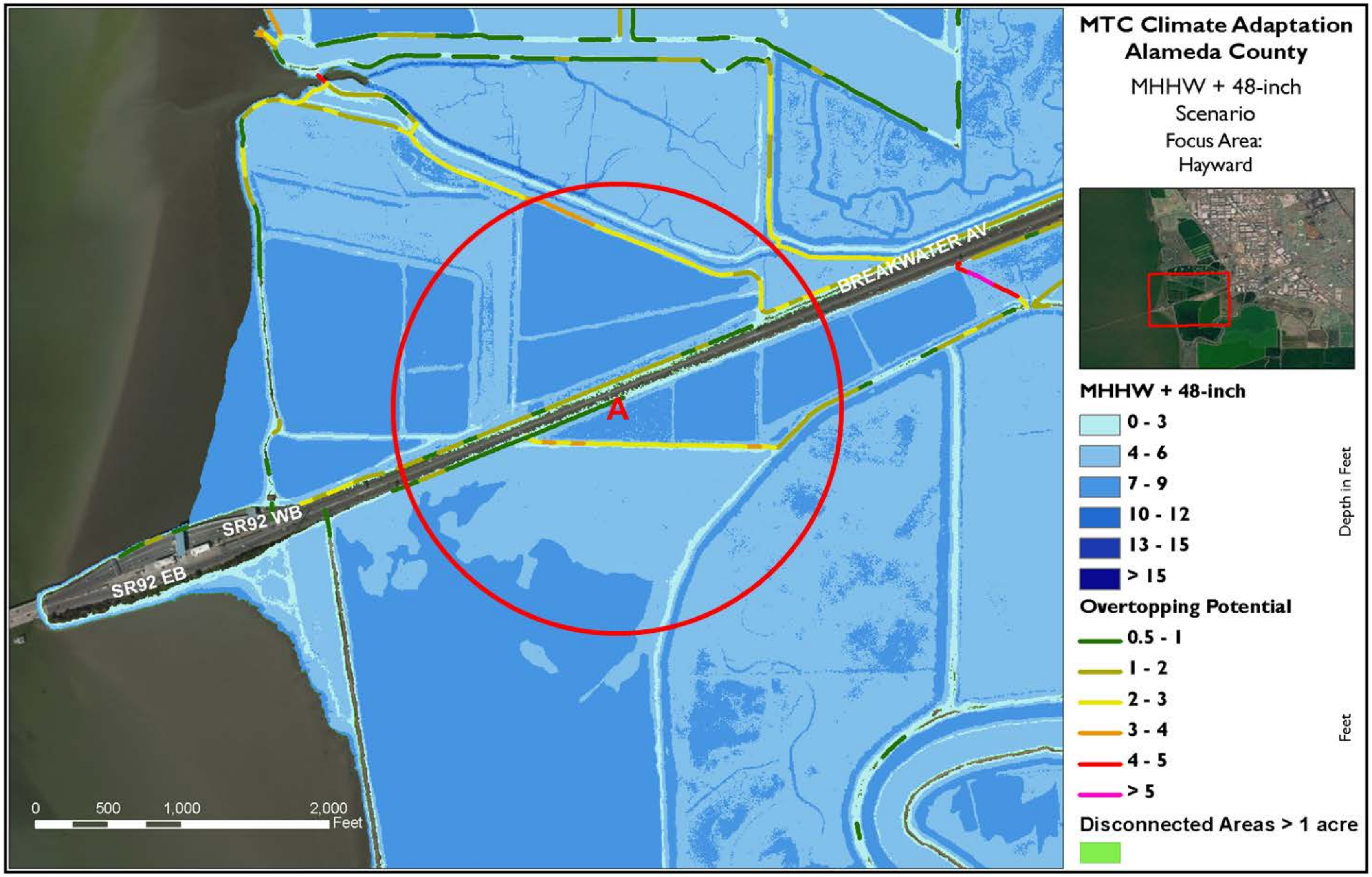

Figure 5. Inundation at Area A (MHHW + 48-inch Scenario)

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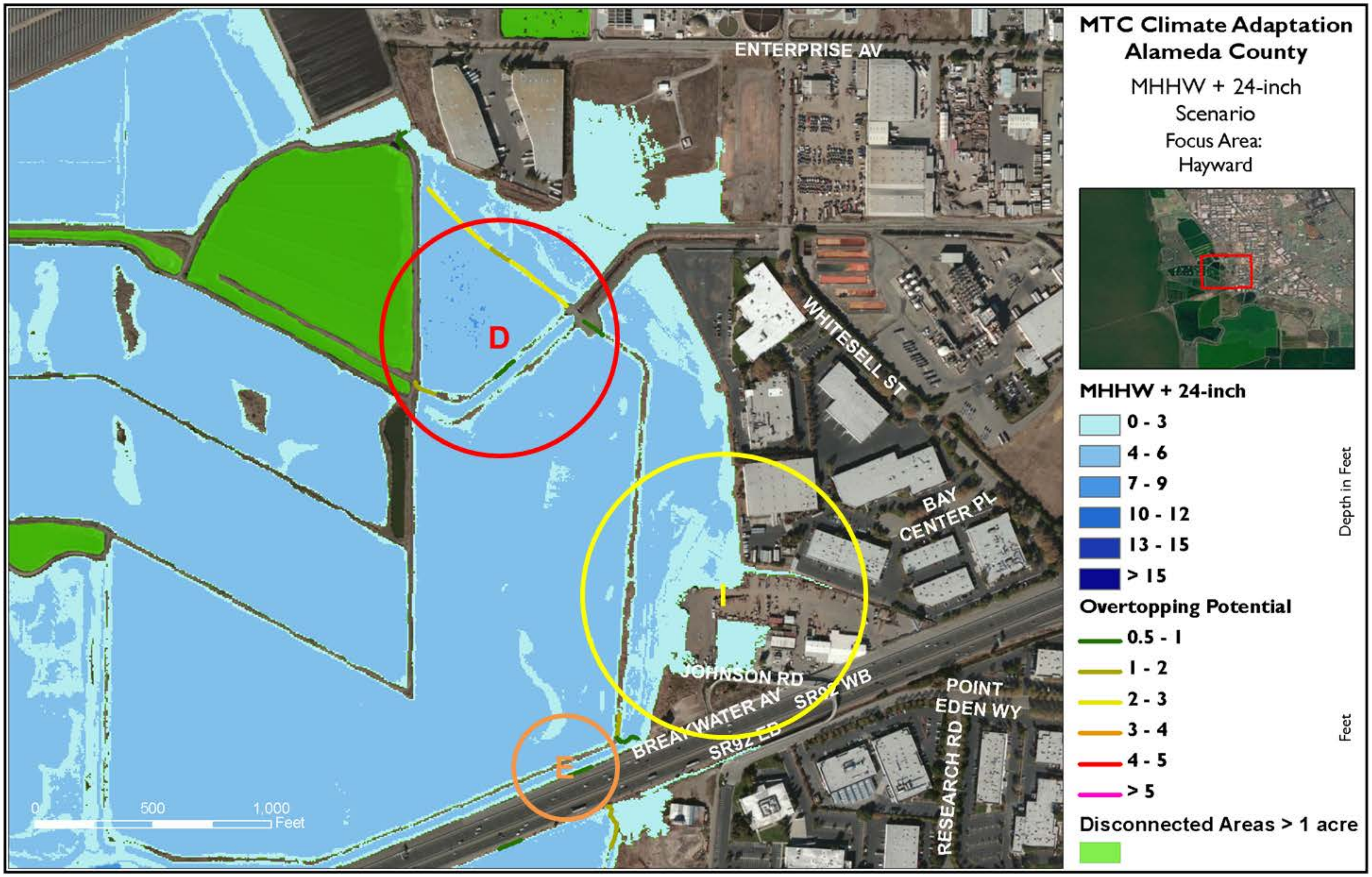


Figure 6. Areas of Inundation Adjacent to SR 92 (MHHW + 24-inch Scenario)

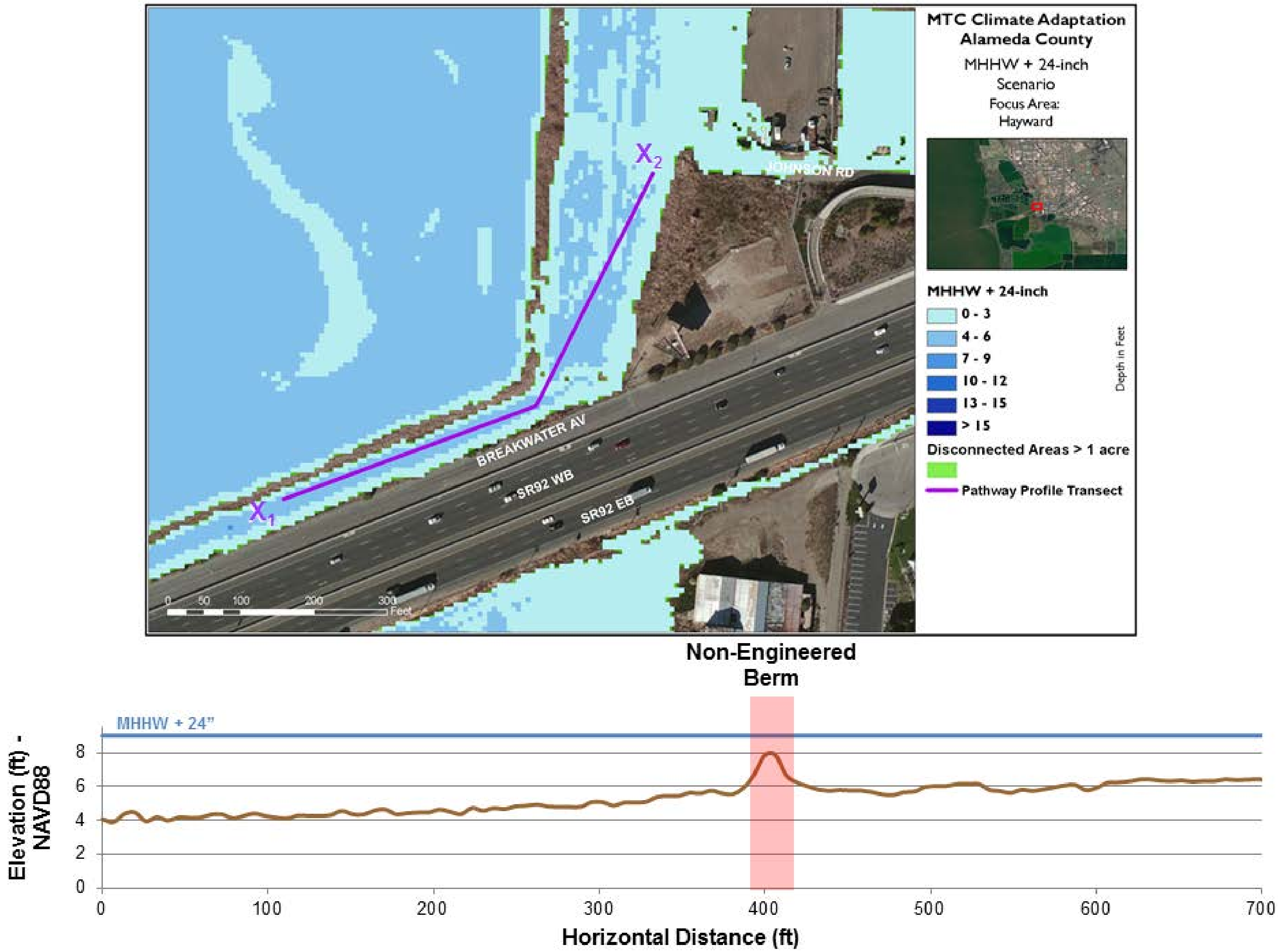


Figure 7. Plan and Profile of Critical Inundation Pathway (Area E) Connecting the Wetland Channel with Inland Inundation Areas

Note: Profile outlined in purple in the plan view. Profile stationing reads from west (X_1) to east (X_2).

4.4 SOUTH OF SR 92

South of SR 92, inundation occurs primarily due to overtopping of non-engineered berms east of the Eden Landing Ecological Reserve. One shoreline inundation area (Area C), one critical inundation pathway (Area F), and one inland inundation area (Area J) were identified in this region. Shoreline inundation areas are presented in Section 4.4.1; critical inundation pathways are presented in Section 4.4.2; and inland inundation areas are presented in Section 4.4.3.

4.4.1 SHORELINE INUNDATION AREAS

One shoreline inundation area (Area C) was identified for the region south of SR 92. Several segments of the non-engineered berm south of Point Eden Way are overtopped at the 48-inch scenario and inundate the industrial areas near Area C. A summary of the shoreline inundation areas is presented below:

- Area C (Figure 8)
    - Overtopping of the non-engineered berm in the northeast area of Eden Landing Ecological Reserve first occurs at the 48-inch scenario with inundation depths of 0-3 feet
    - Eden Landing Road and Arden Road are partially inundated
    - Industrial buildings and parking lots are partially inundated

4.4.2 CRITICAL INUNDATION PATHWAYS

One critical inundation pathway (Area F) was identified south of SR 92, with overtopping first observed in the 24-inch scenario. Given the relatively large extent of inland inundation observed as a result of overtopping at Area F, AECOM sought to verify the pathways of flooding and accuracy of the DEM upon which the inundation maps were based to confirm the likelihood of flooding depicted. The DEM was compared to the original topographic Light Detection and Ranging (LiDAR) data points for this area to confirm that the modeled terrain surface accurately represented the raw LiDAR data. Additionally, the 2014 ESRI World Imagery and aerial photography from Google Earth (2014) were examined to confirm the location of both pathways and surrounding features. These comparisons verified that the DEM adequately captures this area. The extensive inland inundation occurs when a berm located at the landward terminus of a channel near the intersection of Arden Road and Baumberg Avenue (east of Eden Landing Ecological Reserve) is overtopped. The high point of the critical inundation pathway occurs at an elevation of approximately 9 feet NAVD88 at Area F. Figure 10 shows a representative transect of the elevation profile along Areas F starting in the channel and extending inland over the non-engineered berm. The MHHW + 24-inch water level is shown for reference relative to the topography. Key observations for the critical inundation pathways are summarized below:

- Area F (Figure 9 and Figure 10)
  - Narrow channel along the inland side of the non-engineered berm fronting Eden Landing Ecological Reserve at Arden Road connects the flooding from southern areas of Eden Landing Ecological Reserve to inland Area J
  - First occurs at the 24-inch scenario with inundation depths of 0-3 feet
  - Critical water level of approximately 9 feet NAVD88

4.4.3 INLAND INUNDATION AREAS

One inland inundation area (Area J) was identified south of SR 92 (Figure 7 and Figure 8). This extensive area along Arden Road and Trust Way is exposed due to overtopping of non-engineered berms at Area C (48-inch scenario) and overtopping of the critical inundation pathway at Area F (24-inch scenario). A summary of the inland inundation areas is presented below:

- Area J (Figure 8 and Figure 9)
  - Mostly industrial and parking areas
  - Inundation first occurs at the 24-inch scenario with depths of 0-3 feet
  - Source of flooding is Eden Landing Ecological Reserve via Areas F and C

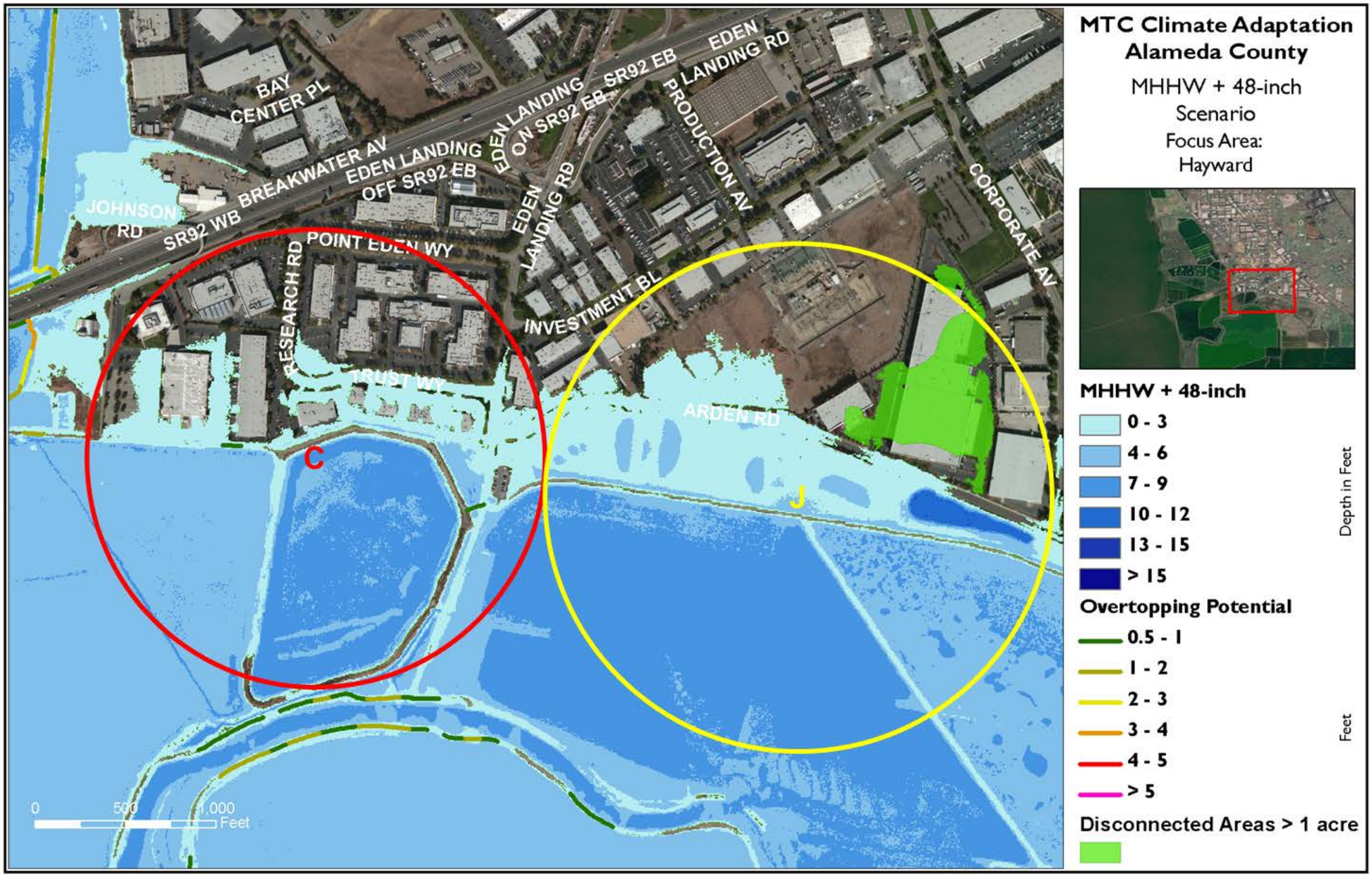


Figure 8. Inundation at Areas C and J (MHHW + 48-inch Scenario)

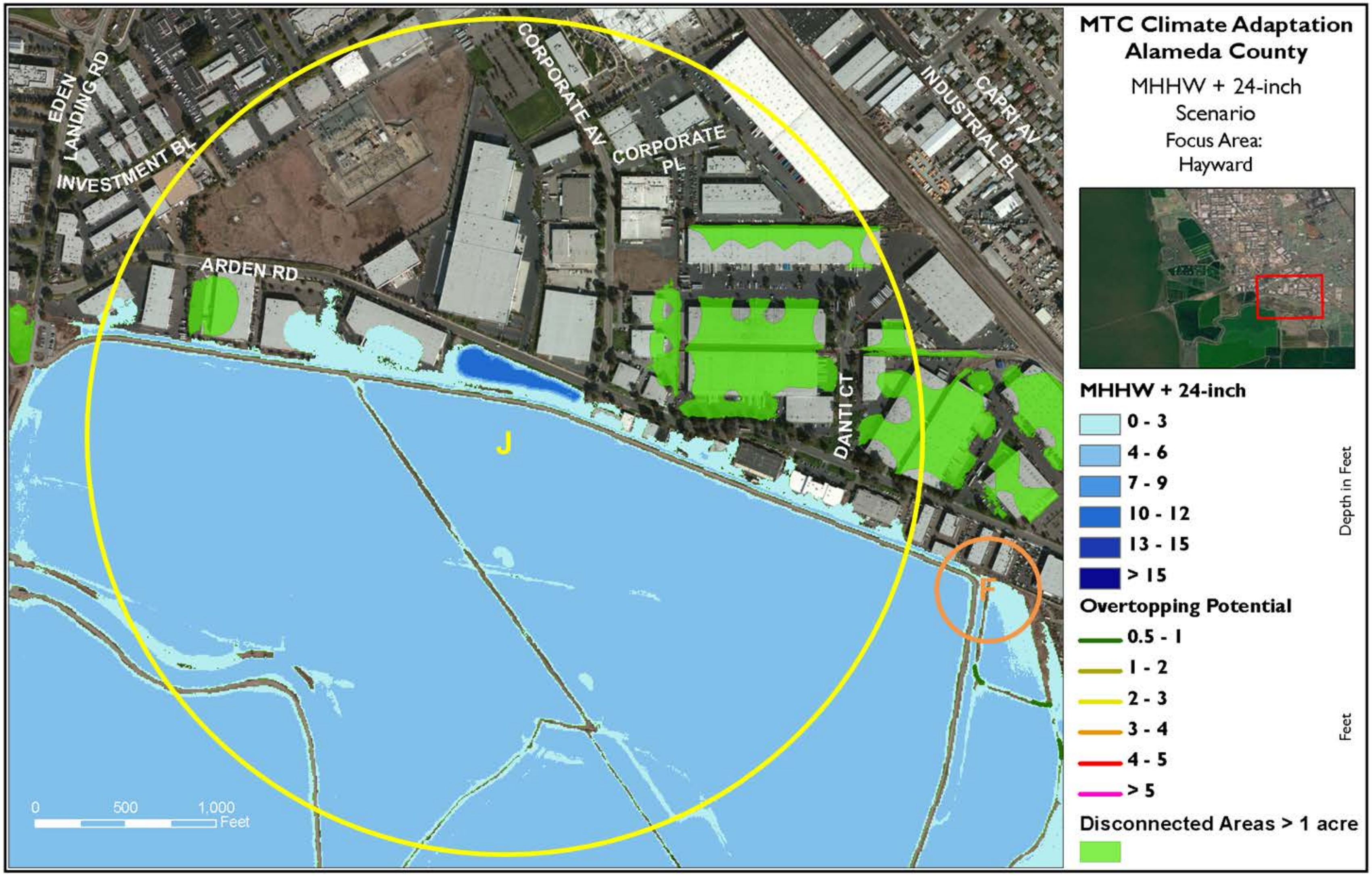
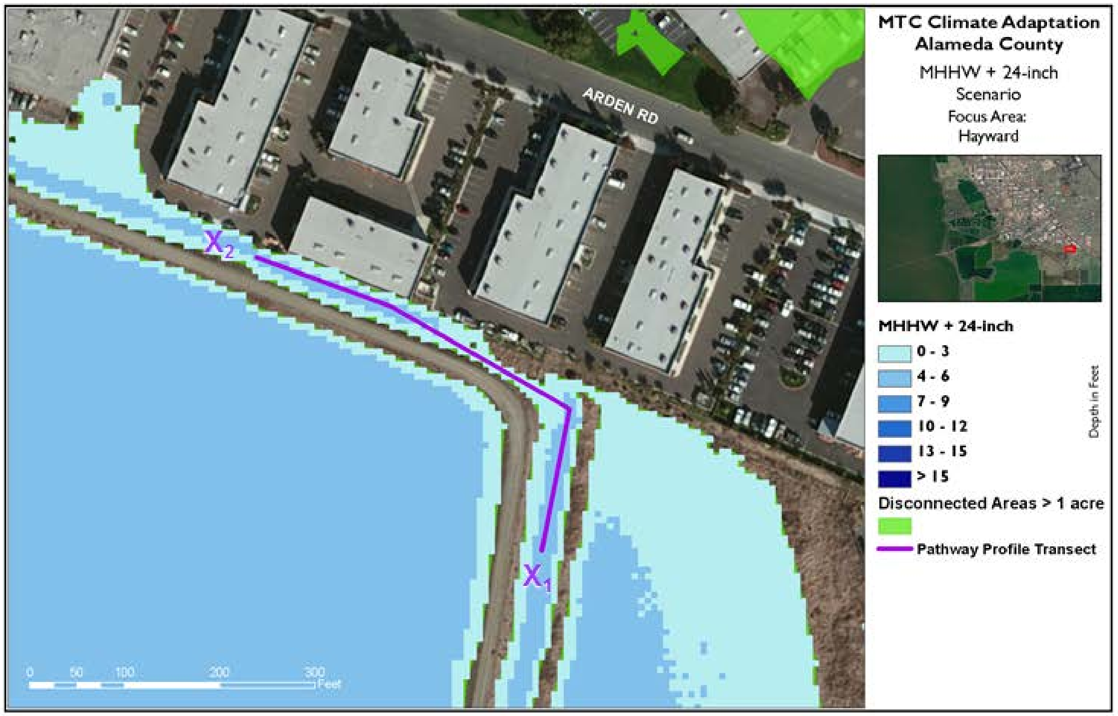


Figure 9. Critical Inundation Pathway F and Inland Inundation Area J (MHHW + 24-inch Scenario)



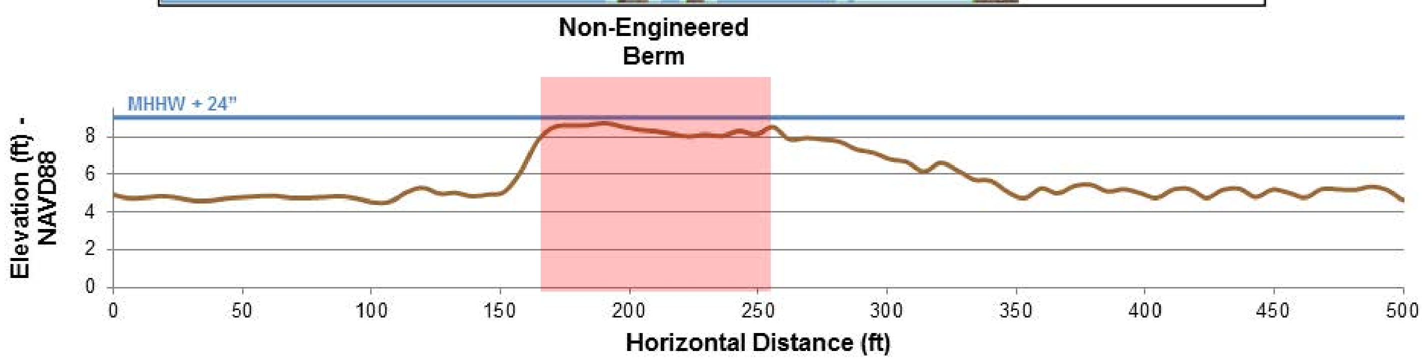


Figure 10. Plan and Profile View of Critical Inundation Pathway (Area F) Connecting the Wetland Channel with Inland Inundation Areas

Note: Profile outlined in purple in the plan view. Profile stationing reads from east (X_1) to west (X_2).

5. TIMING OF ADAPTATION STRATEGIES

The timing of adaptation measure implementation is a key component of climate change adaptation planning. AECOM examined the timing of adaptation measures from the perspective of maintaining the existing level of flood protection in the face of rising sea level. The standard level of design for flood protection along the Bay shoreline is the 100-year (or 1-percent annual chance) flood[6], although in many areas this design criterion is not currently met. For the purposes of this study, the occurrence of various extreme tide levels under different SLR scenarios was evaluated. It should be noted that extreme tide levels presented in this memorandum do not include the effects of waves at the shoreline or the effects of precipitation based runoff and highway drainage and therefore may underestimate true flood risk. FEMA is currently in the process of updating Flood Insurance Rate Maps for this area which provide a more complete assessment of existing flood hazards.

Tidal and managed marshes along the shoreline are exposed to daily inundation under existing conditions and are inundated in the earliest mapped scenario (MHHW + 12-inch) as shown in Table 3. For the managed ponds, if no action is taken to account for rising sea levels, the non-engineered berms that surround these ponds (providing ad-hoc flood protection to inland areas) will become more exposed to storm surge and wave-induced erosion. Over time, this could lead to lower thresholds for permanent inundation and flooding. Implementing adaptation strategies for these features can preserve the value of these natural areas while simultaneously providing flood protection for key assets in the inland areas. To be effective, however, an integrated system-wide approach will be required because of the interconnected nature of these systems.

Table 3 summarizes the timing of flooding for the managed wetlands, ponds, shoreline inundation areas (A-D), critical inundation pathways (E-F), and inland inundation areas (G-J) for various SLR scenarios. As discussed in Section 4, exposure of areas D, I, and J to daily tidal inundation first occurs under the MHHW + 24-inch SLR scenario; however, these areas will be exposed to flooding by extreme tide events at much lower SLR scenarios. For example, assets within areas D, I and J that will be exposed to daily tidal inundation under MHHW + 24-inch could also be exposed to flooding once per year during 12-inch of SLR, or every 5 years under existing conditions. The areas B and G currently experience flooding under an existing 50-year extreme tide while shoreline areas A and C require a coastal storm event greater than the 100-year level before they are flooded under existing conditions[7]. As sea levels increase over time, the level of flood protection for these areas will decrease and flooding will occur at a higher frequency. The reduction in level of flood protection due to SLR is shown in Table 3. If no action is taken, SLR will continue to diminish the level of flood protection afforded by the existing shore protection infrastructure up until the point where the shoreline and inland areas are subject to daily tidal inundation.

In addition to the localized areas of inundation discussed in Section 4, the timing of system-wide inundation is also included in Table 3. System-wide inundation occurs when extensive inland areas

[6] The 100-year flood is typically applied by the Federal Emergency Management Agency (FEMA) for developing Flood Insurance Rate Maps for coastal communities.

[7] It should be noted that localized areas of shoreline flooding may occur at less extreme tides and that the quoted levels of flood protection are based on a high-level examination of the inundation maps and do not represent a rigorous assessment of existing or future flood risk.

are inundated by multiple sources, including the localized inundation areas and pathways identified for lower SLR scenarios. For example, along the shoreline adjacent to the Eden Landing Ecological Reserve, overtopping occurs at two segments of the non-engineered berm in Area C, resulting in daily tidal inundation of the industrial developments at the 48-inch scenario. Although these areas are the earliest sources of inundation, the 72-inch and 96-inch scenarios reveal that the entire non-engineered berm from SR 92 to the southeastern extent of the study area will ultimately be overtopped. In the short term, small-scale localized adaptation measures may be feasible. However, larger-scale integrated adaptation measures will be required in the longer term.

Table 3. Timing of Inundation and Flooding for Inundation Areas within the Hayward Focus Area

		Timing of Temporary Flooding from Extreme Tides (inches of SLR)						
Area	**Permanent Inundation Scenario (inches of SLR)**	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Trangle Marsh, Cogswell Marsh, HARD Marsh, Eden Landing Ecological Reserve South of Mt. Eden Creek	+ 12	Existing	Existing	Existing	Existing	Existing	Existing	Existing
D, E, F, H, I, J, Oliver Salt Ponds, Salt Marsh Harvest Mouse Preserve, Eden Landing Ecological Reserve North of Mt. Eden Creek	+ 24	+ 12	+ 6	Existing	Existing	Existing	Existing	Existing
B, G, Hayward Marsh, Oxidation Ponds South	+ 36	+ 24	+ 18	+ 12	+ 6	+ 6	Existing	Existing
A, C, Oxidation Ponds North	+ 48	+ 36	+ 30	+ 24	+ 24	+ 18	+ 12	+ 6
System-Wide	**+ 72**	**+ 60**	**+ 54**	**+ 48**	**+ 42**	**+ 42**	**+ 36**	**+ 30**

Note: Localized areas of shoreline flooding may occur at less extreme tides. The quoted levels of flood protection are based on a high-level examination of the inundation maps and do not represent a rigorous assessment of existing or future flood risk.

6. PROPOSED ADAPTATION MEASURES

As a part of the MTC Climate Adaptation Pilot Project, several adaptation strategies have been proposed to address the vulnerabilities identified within the Hayward focus area. The following sections summarize the proposed physical strategies for the bayfront marshes and ponds north of SR 92 and for SR 92 itself. It should be noted that the strategies presented are not intended to comprise the full suite of potential strategies that could be implemented to address the physical vulnerabilities within the Hayward focus area.

6.1 MARSHES AND PONDS NORTH OF SR 92

Three potential adaptation strategies were proposed for the marsh and pond areas to the north of SR 92:

- Cooperative land retreat. If the assets are managed collectively, land uses could be shifted when necessary and appropriate protective measures and habitat goals could be established. This strategy requires delineating a segment of berms (existing or engineered) to serve as the landward extent of flood protection; areas outboard of this line of defense would be allowed to transgress naturally and possibly drown with rising sea levels. The outboard areas will attenuate waves and diminish erosion and flood risk; therefore they should be monitored so that additional flood protection elements can be considered and implemented as needed. Critical infrastructure such as landfills and wastewater treatment plants may require additional protection.
- Maintain the existing shoreline alignment by building up the height (and associated width) of the bayfront berms to keep pace with sea level rise. However, many of the existing berms are made of bay mud using local borrow and their maximum height may be limited by geotechnical stability and the availability of material. Water level management within the managed ponds will also become a challenge in the long term. Eventually, rising sea levels may completely surround the berms, leaving them particularly vulnerable to damage from storm surge and wave-induced erosion. Given the challenges associated with this strategy in the long term, this strategy can likely only be used in the short term until a more practical and cost-effective longer-term strategy can be put in place.
- Integrating the Bay trail with a levee alignment. The Bay trail alignment (or an alternate alignment) could be reinforced and raised to provide flood protection. This will provide a hydraulic barrier to the east throughout the focus area. The berm with the integrated Bay Trail alignment would be part of the overall flood defense of this area, assisting in providing multiple lines of defense. Increasing the height of the berm will also increase its width; therefore there may be impacts to surrounding habitats. It is recognized that there will be trade-offs associated with raising the berm and integrated Bay Trail and protecting it in place rather than re-routing the Bay Trail to a more inland location.

6.2 SR 92

Along the SR 92 bridge touchdown, the MTC Climate Adaptation Pilot Project proposed one informational strategy and two physical strategies aimed to reduce the overall physical vulnerabilities in this area:

- SR 92 drainage study (*informational strategy*). Any adaptation strategy that is implemented along the existing SR 92 corridor must take into account the existing SR 92 drainage system, and its interaction with the surrounding channels, ponds, and adjacent areas. The drainage study should quantify the capacity of the existing system, and also investigate how the capacity of the system may change as sea levels rise. Adaptation strategy development must include elements that can increase the drainage capacity of the system, while also considering water quality concerns associated with discharging highway runoff into habitat areas.
- Elevated SR 92 causeway. Constructing an elevated causeway for the SR 92 touchdown would require constructed new pile-supported road sections. Construction would need to be done in a staged manor to minimize traffic disruption, such as constructing the elevated sections on either side of the existing highway, and then removing the existing the highway once construction is complete (similar to the strategy employed for construction of the new Oakland – Bay Bridge span). Although this is a transportation-focused solution, it would also connect the habitat areas to the north and south of SR 92, and provide for a wider array of collective management strategies between the northern and southern areas. This strategy would also maintain view corridors with the Bay and surrounding habitats.
- Engineered structures adjacent to SR 92 touchdown. Engineered structures, such as embankments armored with rip-rap, sea walls, or levees could be constructed adjacent to the roadway. Armoring embankments would reduce wave-induced erosion, but would do little to mitigate rising sea levels. Levees and seawalls would visually cut off the road from views of the adjacent habitats. Levees would require regular maintenance, but could be integrated into the natural environment, unlike seawalls.

7. CONCLUSIONS

Ten key vulnerable areas were identified within the Hayward focus area (Figure 1). Four of these are shoreline inundation areas, two are critical inundation pathways, and four are inland inundation areas. The general hydraulic connections between the areas are presented in Figure 2. The threshold for localized daily tidal inundation of shoreline and inland areas occurs at the MHHW + 24-inch scenario; however, extreme tides (5-year or greater) already threaten assets immediately adjacent to the shoreline under existing conditions. Daily tidal inundation of SR 92 (Area A) as well as extensive inundation of the inland industrial developments occurs at the MHHW + 48-inch scenario; however, extreme tides (50-year or greater) will threaten these areas in the future with just 6 inches to 12 inches of SLR. Hayward Shoreline Interpretive Center is first exposed to inundation at the 24-inch scenario while the landfills near Triangle Marsh are not inundated in any of the mapped scenarios. Overtopped non-engineered berms and wetland channels are the key sources of inundation for these areas. Triangle Marsh, Cogswell Marsh, HARD Marsh, and Eden Landing Ecological Reserve south of Mt. Eden Creek are exposed to daily tidal inundation at the 12-inch scenario. The Oliver Salt Ponds, Salt Marsh Harvest Mouse Preserve, and the remainder of Eden Landing Ecological Reserve are permanently inundated at the 24-inch scenario. Hayward Marsh is exposed to inundation at the 36-inch scenario and the oxidation ponds are completely inundated at the 48-inch scenario. This assessment does not consider natural marsh processes such as marsh accretion, and the topography of the area is assumed to remain constant over time. However, some of the marsh and restoration areas may continue to accrete material and keep pace with sea level rise. If the marsh areas are able to keep pace with sea level rise, they will continue to provide some level of flood protection to the adjacent inland areas.

The earliest source of localized inundation within the Hayward focus area occurs when the banks of the engineered or natural drainage channels overtop; as the internal pond berms begin to overtop, system-wide inundation occurs. In the short term (0-6 inches of SLR), small-scale localized shoreline adaptation measures may protect critical assets from flooding during extreme tides; however, over the longer term (approximately 36 inches of SLR and greater), a large-scale integrated flood protection strategy for the Hayward focus area will be required to prevent extensive flooding during extreme tides.

Adaptation measures should consider the combined impact of coastal storm surge, waves, and roadway drainage and runoff. The cumulative impacts of rainfall runoff storm events occurring during periods of extreme tide levels were not considered in this analysis. Rainfall runoff events will further exacerbate flooding in the watershed. In addition, rising groundwater tables, primarily associated with static SLR, can impact flooding and drainage by reducing infiltration and sub-surface storage of runoff. The existing highway drainage systems will become less effective over time, and the existing drainage systems may become ineffective with higher levels of SLR. Consideration and evaluation of these factors is recommended as a next step.

8. REFERENCES

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Attachment A – Hayward Focus Area Site Visit Photos

Attachment A - Site Visit Photos (March 17, 2014)

Hayward Focus Area – Shoreline Protection (Cogswell Marsh looking South)

Hayward Focus Area – Shoreline Protection (Hayward Marsh looking South)

Hayward Focus Area – Tide Control Structures (Channel between Cogswell Marsh and Hayward Marsh looking inland)

Hayward Focus Area – Tide Control Structures (Channel between Hayward Marsh and HARD Marsh looking towards the Bay)

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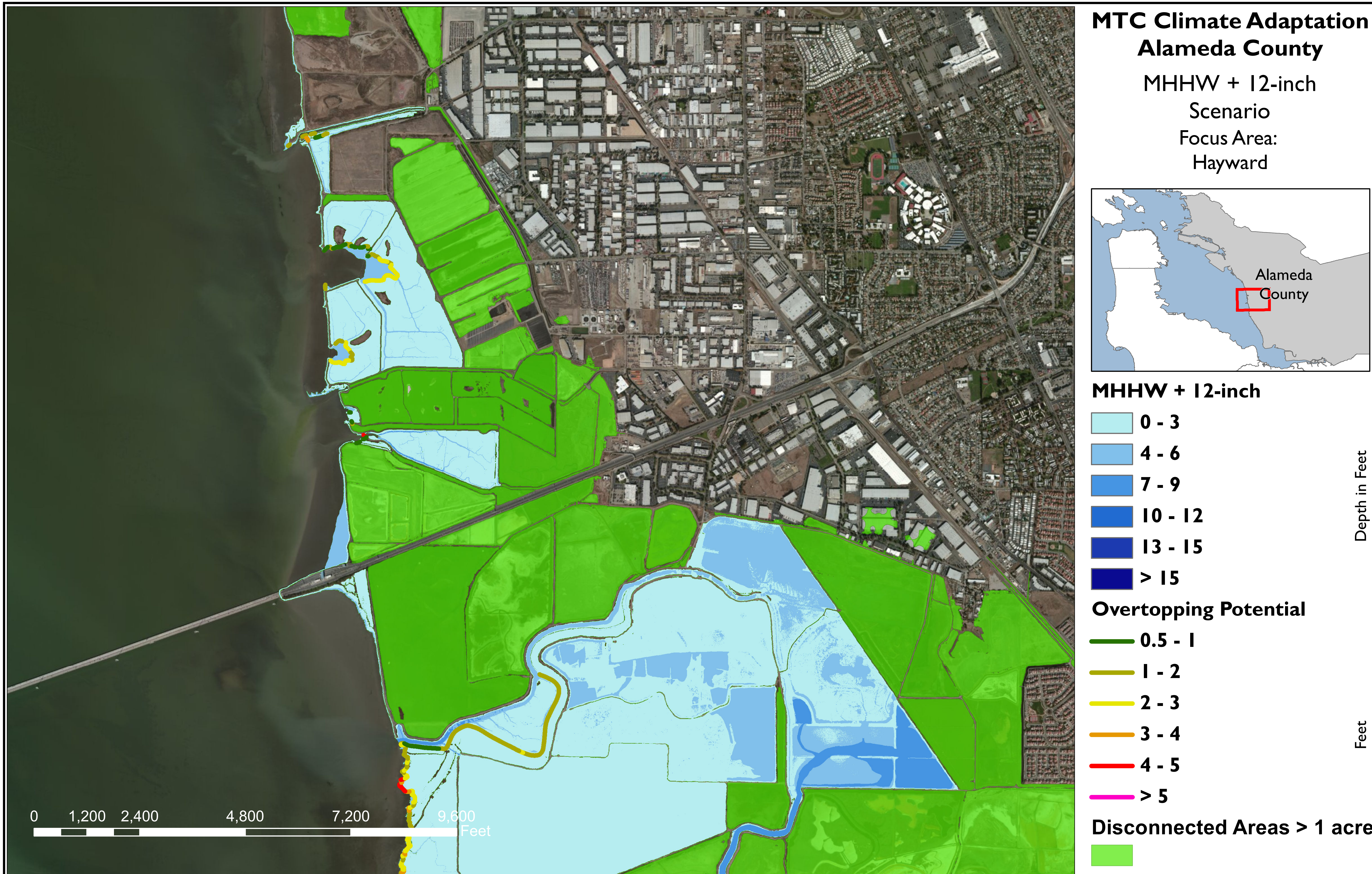
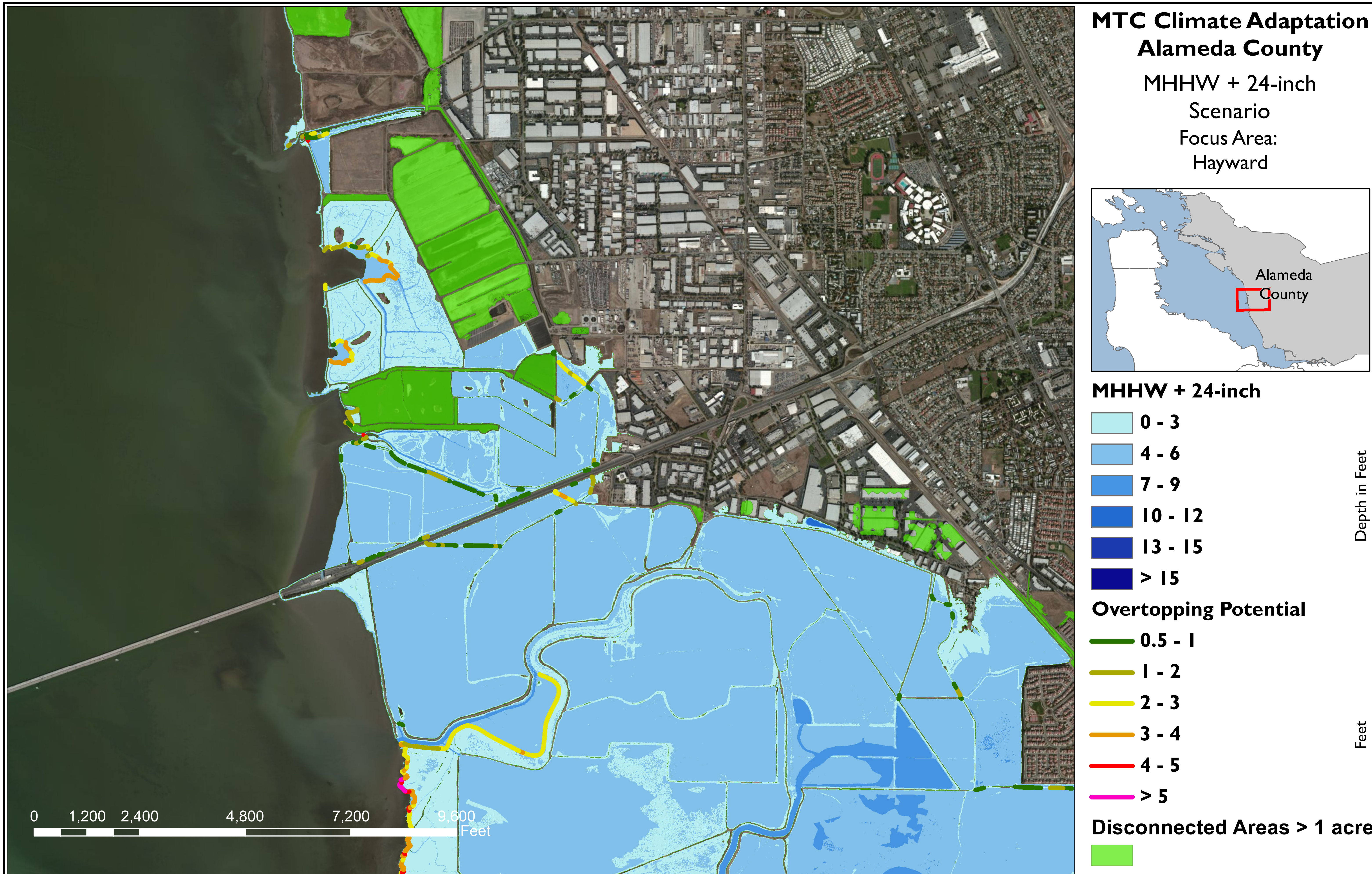
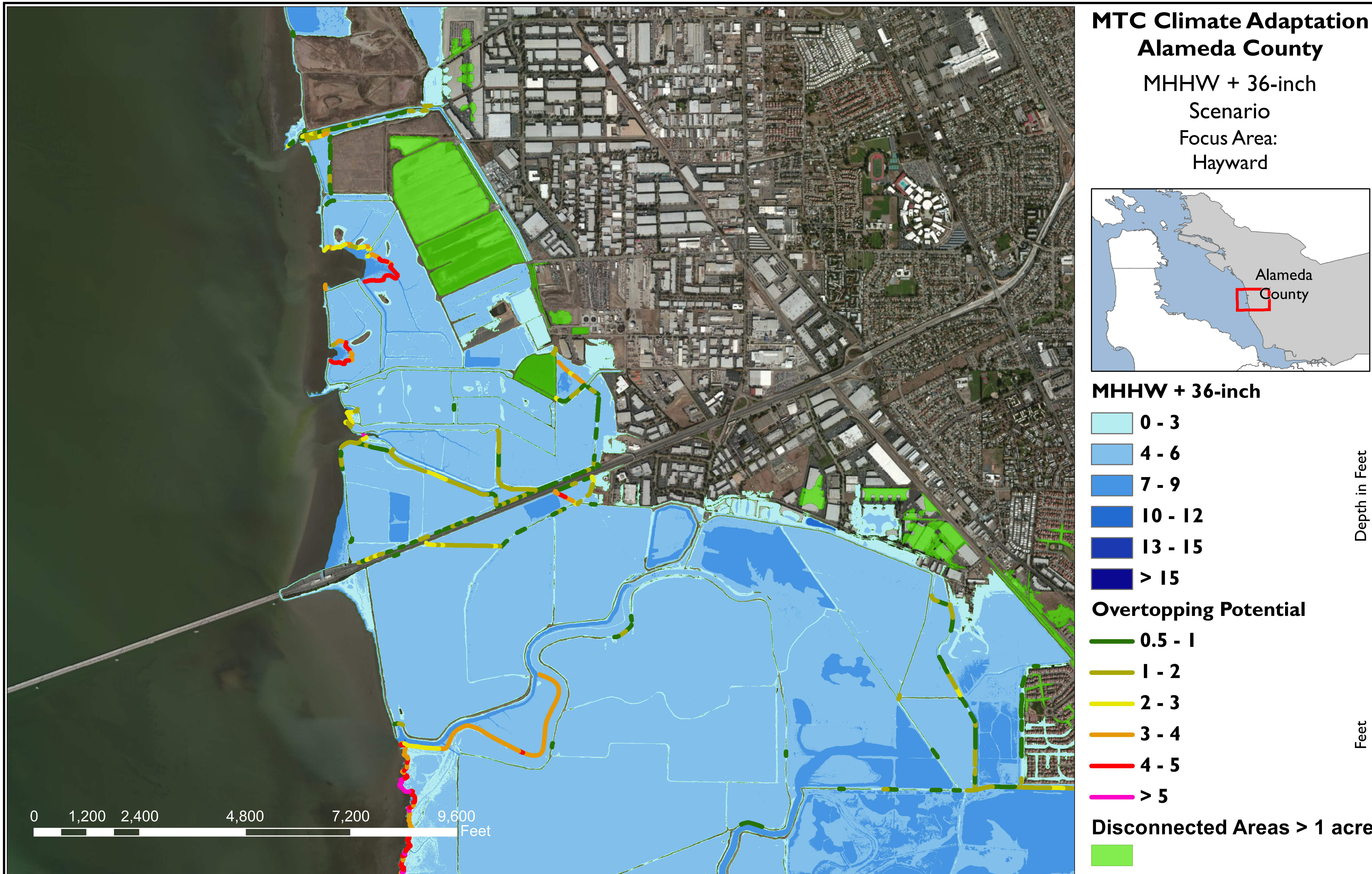
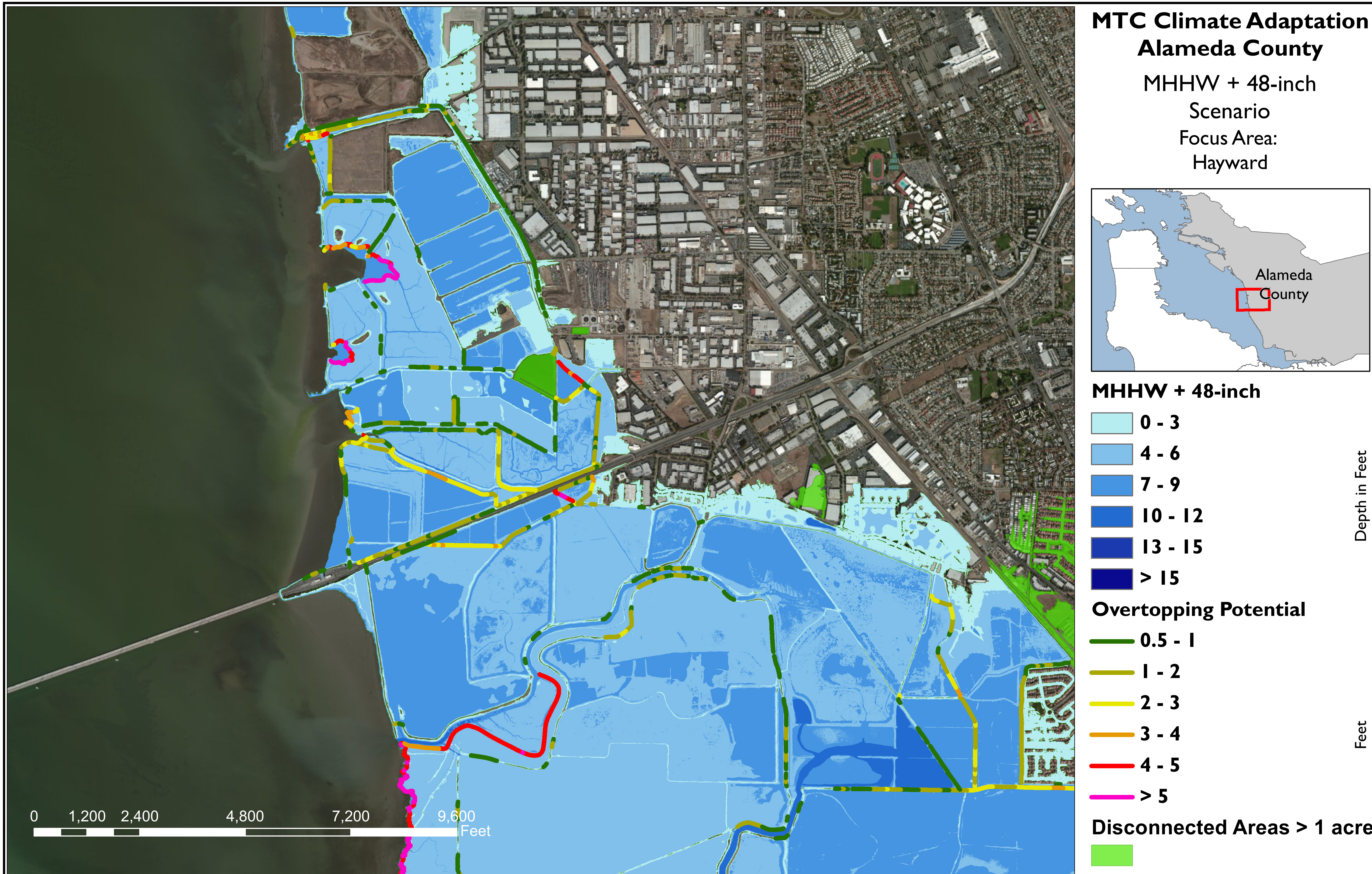
Attachment B – Focus Area Inundation Maps


MTC Climate Adaptation
Alameda County
MHHW + 12-inch
Scenario
Focus Area:
Hayward
Alameda
County
MHHW + 12-inch
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Depth in Feet
Overtopping Potential
0.5 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Feet
Disconnected Areas > 1 acre
0
1,200
2,400
4,800
7,200
9,600
Feet

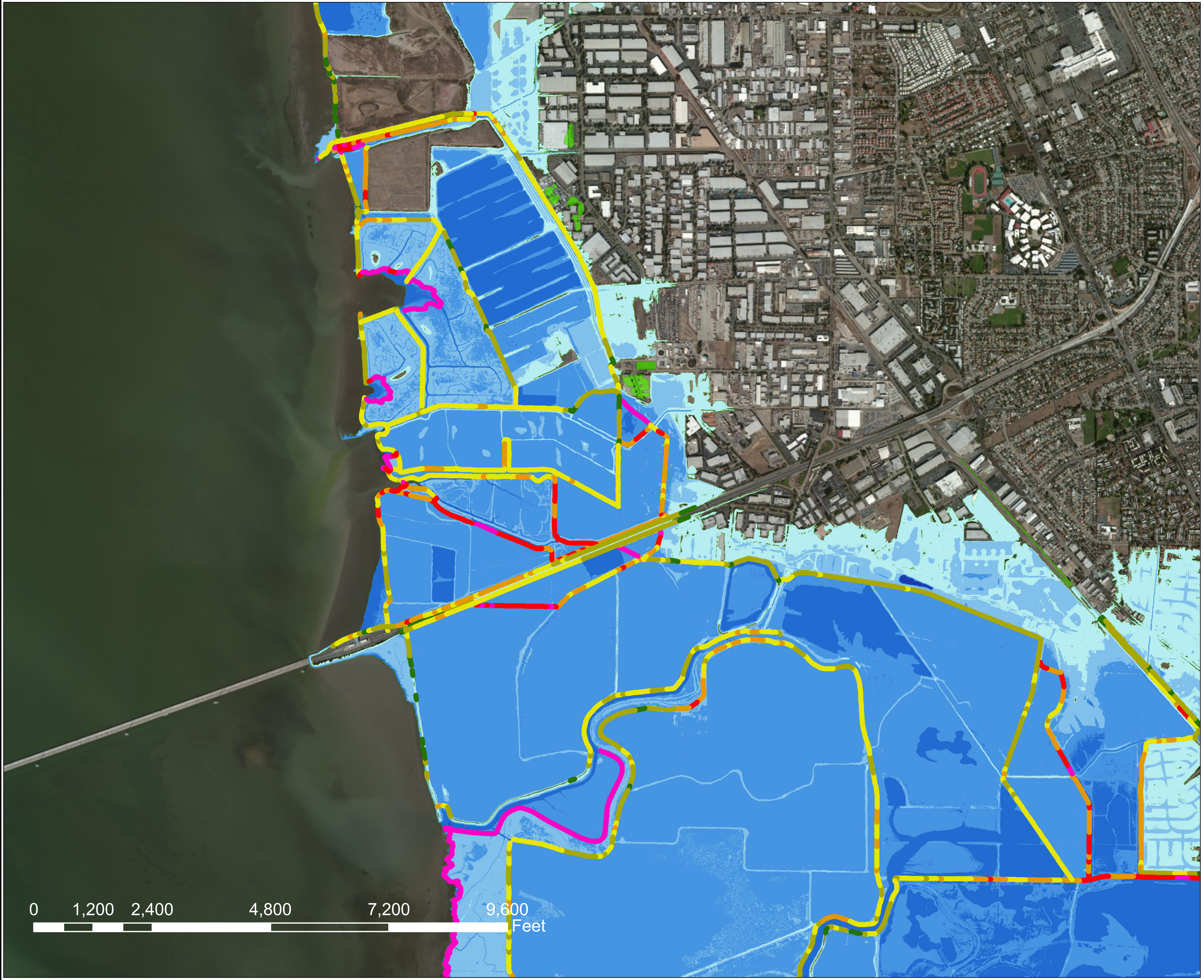


MTC Climate Adaptation
Alameda County
MHHW + 24-inch
Scenario
Focus Area:
Hayward
Alameda
County
MHHW + 24-inch
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Depth in Feet
Overtopping Potential
0.5 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Feet
Disconnected Areas > 1 acre
0
1,200
2,400
4,800
7,200
9,600
Feet


MTC Climate Adaptation
Alameda County
MHHW + 36-inch
Scenario
Focus Area:
Hayward
Alameda
County
MHHW + 36-inch
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Depth in Feet
Overtopping Potential
0.5 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Feet
Disconnected Areas > 1 acre
0
1,200
2,400
4,800
7,200
9,600
Feet



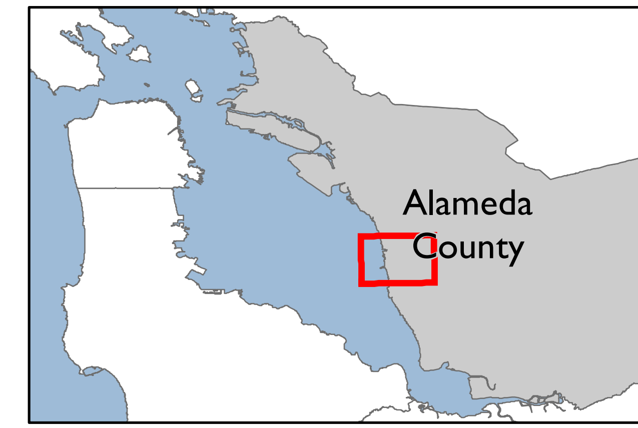
MTC Climate Adaptation
Alameda County
MHHW + 48-inch
Scenario
Focus Area:
Hayward
Alameda
County
MHHW + 48-inch
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Depth in Feet
Overtopping Potential
0.5 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Feet
Disconnected Areas > 1 acre
0
1,200
2,400
4,800
7,200
9,600
Feet



MTC Climate Adaptation
Alameda County

MHHW + 72-inch Scenario

Focus Area: Hayward



MHHW + 72-inch

Depth in Feet

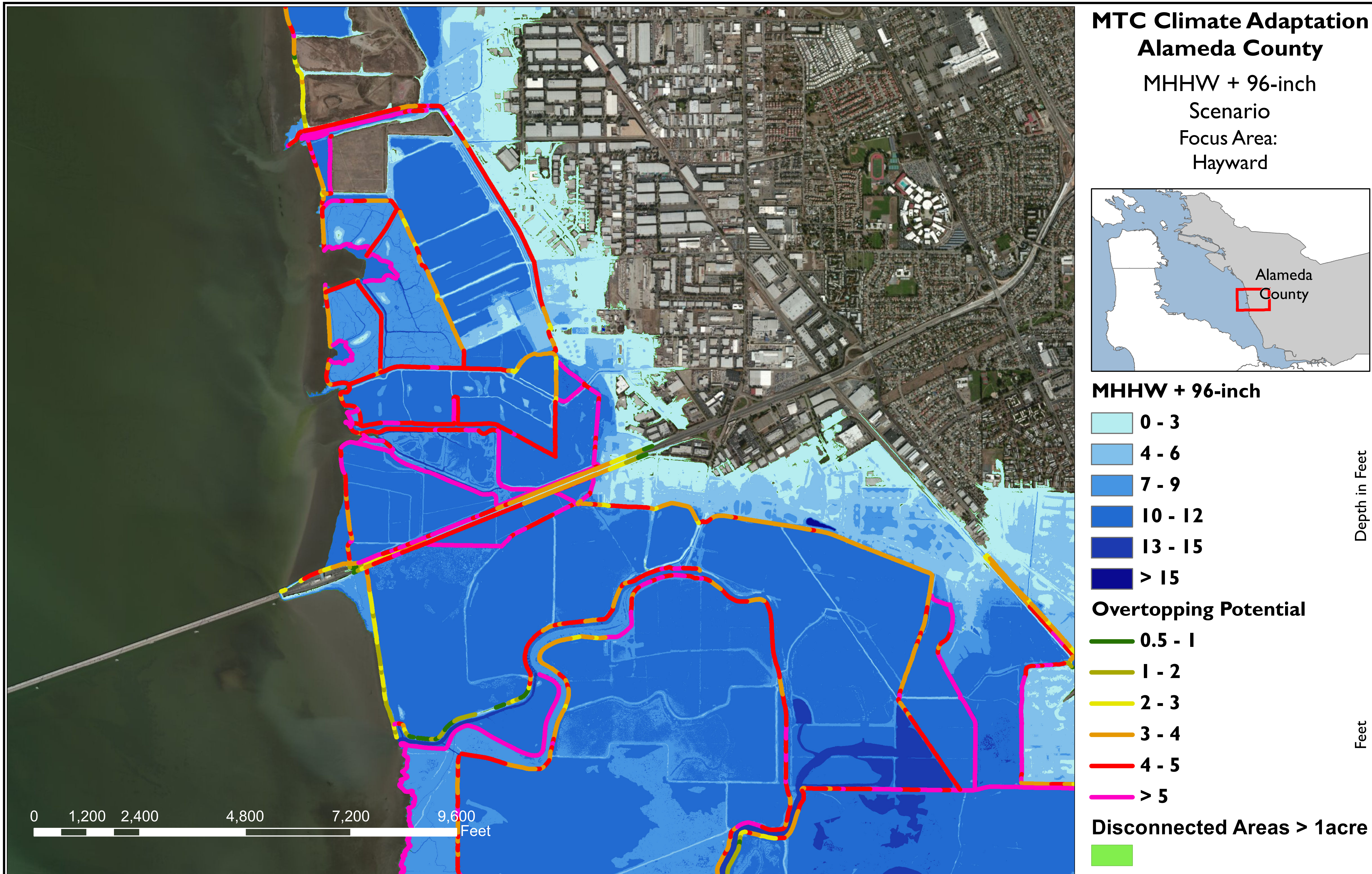
- **0 - 3**
- **4 - 6**
- **7 - 9**
- **10 - 12**
- **13 - 15**
- **> 15**

Overtopping Potential

Feet

- **0.5 - 1**
- **1 - 2**
- **2 - 3**
- **3 - 4**
- **4 - 5**
- **> 5**

Disconnected Areas > 1 acre



MTC Climate Adaptation
Alameda County
MHHW + 96-inch
Scenario
Focus Area:
Hayward
Alameda
County
MHHW + 96-inch
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Depth in Feet
Overtopping Potential
0.5 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Feet
Disconnected Areas > 1acre
0
1,200
2,400
4,800
7,200
9,600
Feet

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Memorandum

To	Wendy Goodfriend, BCDC	Page	1
CC	Claire Bonham-Carter, AECOM		
Subject	Bay Farm Island Focus Area		
From	Jeremy Mull, P.E., Michael Mak, P.E., Kris May, Ph.D., P.E.		
Date	June 25, 2014		

1. INTRODUCTION AND PURPOSE

Bay Farm Island was selected as a focus area for more detailed sea level rise (SLR) exposure analysis and adaptation strategy development as part of the ongoing work by the San Francisco Bay Conservation and Development Commission (BCDC) and Alameda County Flood Control and Water Conservation District (ACFCWCD) to better understand sea level rise, storm surge, and shoreline vulnerabilities in Alameda County. Under a separate project named the Adapting to Rising Tides (ART) Transportation Vulnerability and Risk Assessment Pilot Project (ART) (BCDC et al. 2011), this area was identified as vulnerable to inundation by SLR and coastal storm surge that could impact critical transportation assets and other adjacent assets that support the region. Additional sea level rise inundation maps were created for the Alameda County Sea Level Rise Shoreline Vulnerability Assessment (in progress), which includes the Bay Farm Island focus area within the mapping extent. These inundation maps were examined to better understand the timing of when sea level rise is expected to impact the shoreline and inland areas. The inundation maps showed that an extensive portion of Bay Farm Island, including facilities associated with the Oakland International Airport, would be inundated with as little as 12 inches of SLR (see Figure 1). Prior to identifying key vulnerabilities within the focus area, a first step was taken to verify the accuracy of the initial inundation maps and confirm the likelihood of inundation shown during 12 inches of SLR. Refinements to the inundation maps were made where necessary and are presented in this memorandum.

The purpose of this memorandum[1] is to identify the key areas of vulnerability that exist within the focus area and assess the sources, mechanisms, and timing of inland inundation and flooding to inform the development of adaptation measures, some of which are presented in this memorandum. This technical memorandum should be considered in tandem with other ongoing work in Alameda County, including the current Metropolitan Transportation Commission (MTC) Climate Adaptation Pilot Study, which is conducting a similar level of vulnerability assessments in other areas that have been identified as vulnerable. The following sections provide a description of the Bay Farm Island Focus Area (Section 2), an assessment of exposure to inundation and flooding (Section 3), the verification of topographic features and elevations at several locations (Section 4), identification of key areas of vulnerability (Section 5), recommendations for the timing of adaptation measures (Section 6), potential adaptation measures (Section 7), and conclusions and next steps (Section 8).

[1] This memorandum is funded with qualified outer continental shelf oils and gas revenues by the Coastal Impacts Assessment Program, Fish and Wildlife Service, U.S. Department of the Interior.

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Figure 1. Initial Inundation Maps Showing Inundation of Bay Farm Island with 12 inches of SLR

Note: Inundated areas, including the Oakland International Airport, are shaded in blue.

2. FOCUS AREA DESCRIPTION

Bay Farm Island is a relatively low-lying peninsula that extends from the eastern shoreline of San Francisco Bay. It was historically an island surrounded by several marsh complexes but is now connected to the San Francisco Bay shoreline by artificial land fill and a majority of the marshes have been developed with fill. Located within the City of Alameda and the City of Oakland, key assets include the Oakland International Airport, Oakland Raiders headquarters, the Chuck Corica Golf Complex, and several residential neighborhoods. Bay Farm Island is currently protected from coastal flooding and inundation by several standalone structures and tide gates along the shoreline. In addition, there is a system of levees that protects the shoreline in several areas, most notably around the Oakland International Airport. Placements of rip-rap and revetments protect areas of the shoreline from erosion. The key areas in this assessment include the northern and eastern portions of the Bay Farm Island shoreline along San Francisco Bay and San Leandro Bay, where inundation is first expected to occur during sea level rise and storm surge events. Several sections along this shoreline are known low-lying areas that are already vulnerable to flooding during storm surge events. The section of the shoreline investigated in this focus area is highlighted in Figure 2. Key areas of inundation that needed to be verified during the assessment are presented in Section 4.

Figure 2. Focus Area Shoreline

3. INUNDATION AND FLOODING EXPOSURE

In the discussion that follows, a clear distinction is made between the terms *inundation* and *flooding*. Permanent *inundation* occurs when an area is exposed to regular daily tidal inundation. A permanently inundated area can no longer be used in the same way as an inland area due to the frequency of its exposure to sea water. In contrast, *flooding* occurs when an area is exposed to episodic, short duration, extreme tide events of greater magnitude than normal tide levels. Inland areas may be temporarily flooded during an extreme tidal event while maintaining at least a portion of their functionality once the floodwaters recede. However, sensitive assets may suffer irreversible damage if exposed to any amount of water, even temporarily. The term flooding, as it is used throughout this memorandum, is therefore a temporary condition that results from a storm event rather than the permanent inundation due to daily high tides.

To assess portions of the shoreline that are exposed to inundation and flooding within the Bay Farm Island focus area, six sea level rise inundation mapping scenarios were examined (Table 1). Inundation maps were created for each of the scenarios using the methodology developed by the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (Marcy et al. 2011). The scenarios were developed by adding different amounts of sea level rise onto the elevation of the existing conditions daily high tide level (represented by the Mean Higher High Water (MHHW) tide). The MHHW reference water levels used in this analysis were derived from MIKE21 model output from a regional San Francisco Bay modeling study completed as part of the Federal Emergency Management Agency (FEMA) San Francisco Bay Area Coastal Study [2] (DHI 2011). The modeling study spanned a 31-year period from January 1, 1973 to December 31, 2003. The MHHW tidal datum was calculated using the portion of the model output time series corresponding to the most recent National Tidal Datum Epoch (1983 through 2001), which is a specific 19-year period adopted by NOAA to compute tidal datums. In accordance with the most up-to-date sea level rise projections, the following scenarios were evaluated for the present study: 12 inches, 24 inches, 36 inches, and 48 inches of sea level rise above existing MHHW. In addition to these scenarios, 72 inches and 96 inches above MHHW were also evaluated, but these water levels are outside the range of current scientific predictions for sea level rise within this century and, therefore, do not correspond with permanent inundation scenarios that are likely to occur before 2100 (NRC 2012). These scenarios are included to evaluate important extreme flooding scenarios that could happen during storm surge events with lesser amounts of sea level rise.

The initial inundation maps for this focus area were developed by AECOM as part of the Alameda County Sea Level Rise Shoreline Vulnerability Assessment for BCDC and ACFCWCD. The maps show the extent of inland inundation, inundation depths, and the depth of "overtopping potential" along the shoreline. Overtopping potential refers to the condition where the water surface elevation associated with a particular reference water level exceeds the elevation of the shoreline asset. The depth of overtopping potential at each shoreline segment is calculated by taking an average of several depths over the length of the segment. Note that the overtopping calculations represent an average of inundation depths over a specified length of the shoreline and do not show depths less than 0.5 feet to account for the limits in the vertical accuracy of the DEM and the sea level rise inundation mapping process. Therefore in some areas on the inundation maps, inundation over a shoreline feature may be shown with no corresponding overtopping depth, if the overtopping depth is

[2] www.r9coastal.org

less than 0.5 feet. This assessment is considered a planning-level tool only, as it does not account for the physics of wave runup 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 mapping scenarios are listed in Table 1. The revised inundation maps created for this assessment are presented in Attachment A**.**

Table 1. Sea Level Rise Inundation Mapping Scenarios

Mapping Scenario	Reference Water Level	Applicable Range for Mapping Scenario (Reference +/- 3 inches)
Scenario 1	MHHW + 12 inch	MHHW + 9 – 15 inch
Scenario 2	MHHW + 24 inch	MHHW + 21 – 27 inch
Scenario 3	MHHW + 36 inch	MHHW + 33 – 39 inch
Scenario 4	MHHW + 48 inch	MHHW + 45 – 51 inch
Scenario 5	MHHW + 72 inch	MHHW + 69 – 75 inch
Scenario 6	MHHW + 96 inch	MHHW + 93 – 99 inch

It is important to understand that the reference water levels listed for each mapping scenario can occur due to a variety of hydrodynamic conditions by combining different amounts of sea level rise with either a daily[3] or extreme high tide. For example, Scenario 3 (MHHW + 36 inch) represents a water level reached by a daily high tide with 36 inches of sea level rise, and we subsequently refer to this scenario as 36 inches of SLR. This scenario also represents a 50-year extreme tide with no sea level rise (i.e., existing conditions). To expand the range of extreme tide and sea level rise scenarios represented by each of the six mapping scenarios, a +/- 3 inches tolerance was added to each reference water level to increase its applicable range. For example, Scenario 3 (MHHW + 36 inch) is assumed to be representative of all extreme tide/sea level rise combinations that produce a water level in the range of MHHW + 33 inches to MHHW + 39 inches. By combining different amounts of sea level rise and extreme tide levels, a matrix of water level scenarios was developed to identify the various combinations represented by each inundation map.

The matrix of sea level rise and tide scenarios is presented in Table 2. Values are shown in inches above the existing conditions MHHW level. The coloring shown matches the coloring in Table 1 and indicates the different combinations of sea level rise and extreme tide scenarios represented by each inundation map. Note that Scenarios 5 and 6 correspond only to extreme tide events as they are outside of the range of projections for probable sea level rise over the next century. The first row of the table shows values for existing conditions. For example, to read Table 2, the inundation map that represents MHHW + 36 inches (Scenario 3), would also represent a 1-yr event with 24 inches of sea level rise, a 2-yr event with 18 inches of sea level rise, a 5-yr event with 12 inches of sea level rise,

[3] Mean Higher High Water (MHHW) is used as a surrogate for the average daily high tide. MHHW is the average of the higher high water level of each tidal day observed over the National Tidal Datum Epoch. It should be noted that. The actual higher high tide that occurs on any given day will be higher or lower than MHHW. MHHW is approximately 6.6 ft NAVD88 within this focus area.

etc. Equivalent water levels for the MHHW + 12 inch, MHHW + 24 inch, MHHW + 36 inch, MHHW + 48 inch, MHHW + 72 inch, and MHHW + 96 inch mapping scenarios can be determined similarly by tracking the color coding through the table. Alternatively, this matrix could be used to plan for a particular level of risk. For example, to examine infrastructure exposure to a 100-yr extreme tide event with an estimated 6 inches of sea level rise, the MHHW + 48 inch mapping scenario could be examined. Using this approach, it is possible to assess flood risk to assets at various time scales and frequency of flooding.

Table 2 . Matrix of Water Levels Associated with Sea Level Rise and Extreme Tide Scenarios

	Daily Tide	Extreme Tide (Storm Surge)						
Sea Level Rise Scenario	**Water Level above MHHW**	**1-yr**	**2-yr**	**5-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**
Existing Conditions	0	14	19	23	27	32	36	41
MHHW + 6 inch	6	20	25	29	33	38	42	47
MHHW + 12 inch	12	26	31	35	39	44	48	53
MHHW + 18 inch	18	32	37	41	45	50	54	59
MHHW + 24 inch	24	38	43	47	51	56	60	65
MHHW + 30 inch	30	44	49	53	57	62	66	71
MHHW + 36 inch	36	50	55	59	63	68	72	77
MHHW + 42 inch	42	56	61	65	69	74	78	83
MHHW + 48 inch	48	62	67	71	75	80	84	89
MHHW + 54 inch	54	68	73	77	81	86	90	95
MHHW + 60 inch	60	74	79	83	87	92	96	101

Note: All values in inches above existing conditions MHHW at Bay Farm Island Focus Area. The extreme tide levels above MHHW were derived from the FEMA MIKE 21 model output. Color coding indicates which combinations of sea level rise and extreme tides are represented by the mapping scenarios shown in Table 1. Cells with no color coding do not directly correspond to any of the mapping scenarios shown in Table 1.

4. KEY FOCUS AREA SITE ASSESSMENTS

By combining the information available in the SLR and tide scenarios matrix (Table 2) with the results of the inundation mapping and overtopping potential calculations, shoreline exposure to inundation/flooding and the timing of exposure can be evaluated. The initial inundation maps from the Alameda County Sea Level Rise Shoreline Vulnerability Assessment indicated that wide-spread inundation could occur with 12 inches of SLR. According to the matrix, the inundation that occurs with 12 inches of sea level is similar to what could occur annually under existing conditions during a King Tide Event (1-year event). However, this degree of flooding does not currently occur during typical Kind Tide conditions. AECOM therefore sought to verify the pathways of flooding as well as the accuracy of the 2-meter resolution digital elevation model (DEM) and 2010 LiDAR data[4]. A detailed review of the inundation maps, inundation depth grids, and overtopping potential calculations revealed low elevations in the DEM at five sites that were acting as critical pathways for inland inundation at low SLR scenarios (Figure 3). The AECOM team performed site visits on March 5, 2014 and March 30, 2014 to verify the elevation of these areas with a visual inspection of the shoreline (see Attachment B for the site visit photos). Only areas with localized inundation pathways or distinct topographic features (e.g., vertical walls) were examined in this verification step. Broad stretches of shoreline that were shown as inundated on the inundation maps were not evaluated.

The site visits and a review of the orthoimagery (2010) from the LiDAR data collection and aerial photography from Google Earth (2014) revealed two vertical structures (one seawall and one wing-wall) that were not fully captured in the DEM at Sites A and B. It is important to note that the bare-earth (Class 2) LiDAR data were used exclusively to generate the DEM. In the bare-earth LiDAR, all vegetation, buildings, bridges, and many coastal protection structures (e.g., standalone seawalls) are typically removed. Furthermore, any seawalls or narrow structures that are not removed from the bare earth data may be too narrow to be fully resolved by the 1-m spaced LiDAR data points. A review of the inundation depth grids further indicated that low elevations in the DEM at Sites C, D, and E along Doolittle Drive were pathways for inland inundation at low SLR scenarios. Although accurate, the 2-m resolution DEM is coarse enough to smooth over high elevation features, including the crests of small levees or the crown of a road, that also provides flood protection.

Although the exact dimensions of these features were not fully captured in the bare-earth LiDAR and/or DEM, there were enough raw LiDAR data points to accurately determine the high point elevations. The DEM at these five sites was compared to the original topographic LiDAR data points in these areas to confirm that the modeled terrain surface of the DEM accurately represented the LiDAR data. If there were distinct differences found between the elevations in the DEM, the elevations in the LiDAR data, and the observations from the site visit, the DEM at each site was modified to reflect the most reasonable or more accurate elevations. After modifying the DEM, the shoreline delineation used for the overtopping potential assessment was adjusted to coincide with the vertical structures and high points of Doolittle Drive. The inundation mapping and overtopping analyses were redone for each sea level rise scenario with the revised DEM to verify how these modifications affected the inundation mapping, and to review and confirm the revised exposure level and shoreline vulnerabilities. The revised inundation maps are found in Attachment A.

[4] A 2-meter digital elevation model (DEM) was developed from the 2010 LiDAR data collected by the United States Geological Survey (USGS) and National Oceanic Atmospheric Administration (NOAA) as part of the California Coastal Mapping Program (CCMP).

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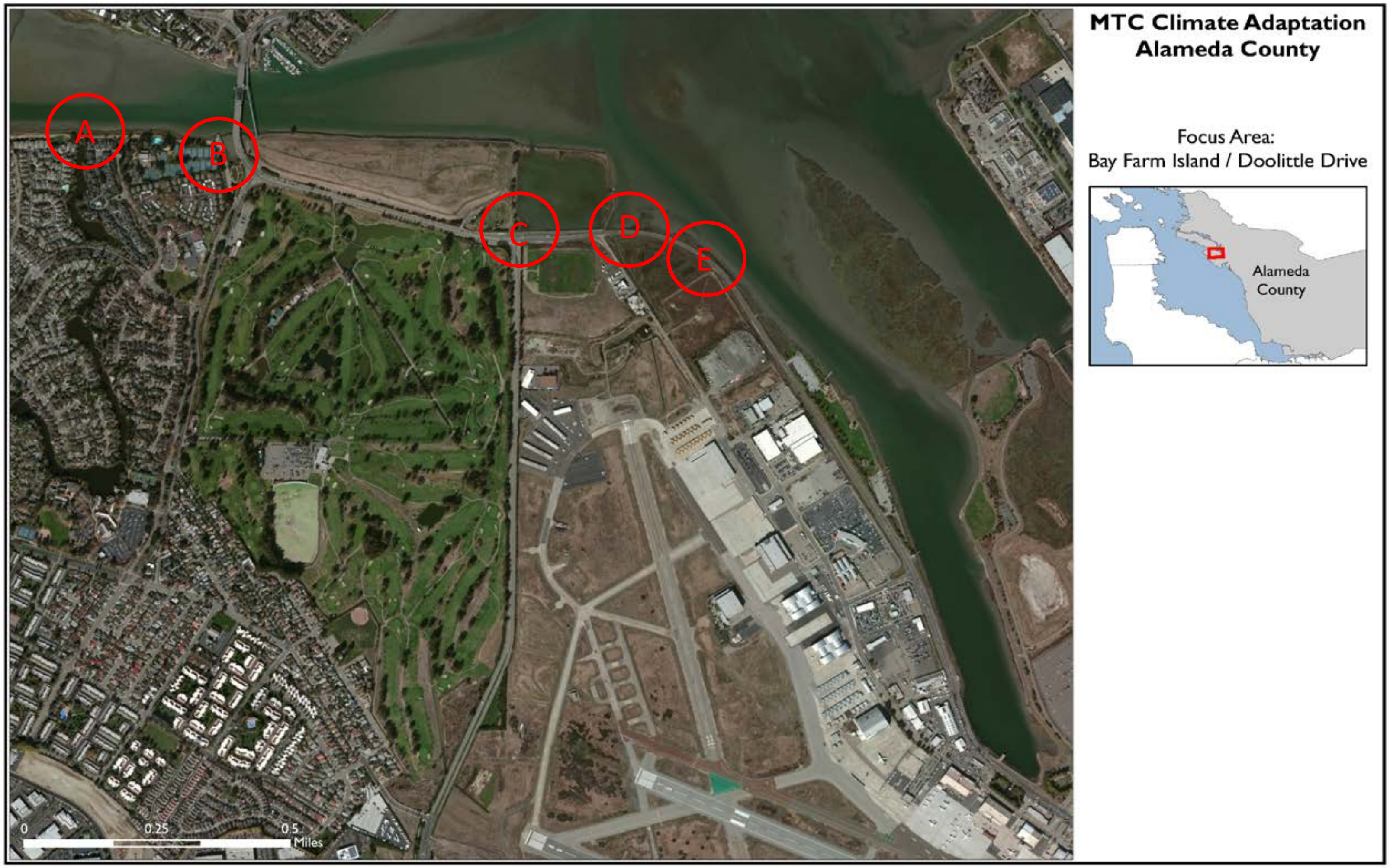

Figure 3. Sites In The DEM Contributing To Inundation In Low SLR Scenario

A summary of the modifications to the topographic DEM are presented in Table 3. For each site that was reviewed, the original DEM elevations, average elevations in the LiDAR data, modified DEM elevations, and the first SLR scenario when the site is overtopped[5] is listed in Table 3. A detailed description of the modifications made to the DEM at each site is provided in the following sections.

Table 3: Modified Low-Lying Areas in the DEM Contributing to Inundation

Site	Average DEM Elevation (feet NAVD88)	SLR Scenario of First Overtopping (inches SLR)	Approximate Wall Height from Ground (feet)	Average LiDAR Elevation (feet NAVD88)	Modified Elevation (feet NAVD88)	Revised SLR Scenario of First Overtopping (inches SLR)
A. Tide Gate Structure						
West Segment	10.0	36	2.0	10.0	NA	36
East Segment	9.0	36	2.0	9.5	9.5	36
B. Veterans Court Seawall						
North Segment	7.2	24	3.0	10.0	10.0	48
Middle Segment	5.9	12	3.0	10.0	10.0	48
South Segment	7.5	12	3.0	10.0	10.0	48
C. Doolittle Drive/Harbor Bay Parkway Intersection	8.5	24	NA	9.0	9.0	36
D. Doolittle Drive	8.5	24	NA	9.0	9.0	36
E. East Doolittle Drive	8.5	24	NA	9.0	9.0	36

NA = No change or not applicable

Note: Average DEM elevations indicate the average of elevation multiple DEM grid cells along each feature. Average LiDAR elevations indicate the average of multiple elevation points along each feature.

4.1 Site A - Tide Gate Structure

Site A is a tide gate structure with low wing-walls located nearly 0.3 miles west of the Doolittle Road/Bay Farm Island Bridge (Figure 4). The berm behind the tide gate structure and wing-walls is at a lower elevation than the top of the wing-walls and the adjacent shoreline. The wing-walls are an engineered structure which protects the backshore area and lagoon from wave action. It also

[5] The sea level rise scenario when the site is first overtopping has been approximated based on the mapped sea level rise inundation scenarios (e.g., 12”, 24”, 36”, 48”). The actual sea level rise scenario which results in overtopping may be less than this amount (i.e., if the SLR scenario of first overtopping is 36 inches, overtopping is first observed in this mapped scenario, but overtopping may occur as early as 25 inches). Refined shoreline tools have been developed for this area that can estimate the overtopping threshold within 6 inch increments, and these tools can be used for future updates to this assessment.

protects the backshore area from scour during periods of discharge from the lagoon. Overtopping at this location will expose the adjacent residential neighborhood to flooding, and during permanent inundation above the wall, the discharge point for stormwater runoff out of the lagoon will be eliminated.

Figure 4. Site A – Tide Gate Structure west of the Doolittle Road/Bay Farm Island Bridge

The wing-walls consist of two segments which are constructed approximately 2 feet above the backshore ground elevation. The average DEM elevation of the west segment was 10.0 feet NAVD88, and overtopping was expected to begin occurring at 36 inches of SLR based on the initial inundation maps. The average DEM elevation of the east segment was 9.0 feet NAVD88, and overtopping was also expected to begin occurring at 36 inches of SLR. The average LiDAR elevations of the walls are approximately 9.5 feet NAVD88, so low DEM elevations on the east segment were modified to reflect this elevation. The low-lying elevations of the backshore area on the DEM were verified to be represented correctly and were not adjusted. After modifications to the topographic DEM were completed, the inundation maps were revised using the new DEM. The new inundation maps in Attachment A show that the east section of the wing-wall is still expected to be overtopped at 36 inches of SLR (approximately 9.6 feet NAVD88). The overtopping potential lines on the inundation maps do not show overtopping over both segments of the wing-wall until 48 inches of SLR. The original DEM elevations, average LiDAR elevations, modified DEM elevations, and lowest overtopping scenarios for Site A are listed in Table 3.

Inundation of the residential areas adjacent to the lagoon will begin at 36 inches of SLR. Inundation will occur from overtopping of the tide gate wing-walls and also via pathways originating from the adjacent Corica Golf Course that is also flooded during this scenario. Residential neighborhoods located more inland will be protected from 36 inches of SLR but will begin to experience inundation at 48 inches of SLR.

4.2 Site B - Veterans Court Seawall

Site B includes a 3 feet-high seawall located immediately west of the Doolittle Drive/Bay Farm Island Bridge along the seaward side of Veterans Court (Figure 5), and a stretch of shoreline just west of the seawall in front of the Harbor Bay Club (Figure 6) with loose rock protection from a former seawall. A detailed review of the DEM and inundation mapping in this area showed that the site served as a critical inundation pathway with 12 inches of SLR.

In the DEM, the average elevation of the north segment of the seawall was 7.2 feet NAVD88, and it was projected to begin overtopping at 24 inches of SLR based on the initial inundation maps. The average elevations of the middle and south segments of the seawall were 5.9 feet and 7.5 feet NAVD88 respectively, and they were projected to begin overtopping with 12 inches of SLR. This location is the primary pathway for all of the inundation in the Bay Farm Focus area with 12 inches of SLR under the initial inundation mapping. However, from the site visit and the initial review of the DEM, it was apparent that the elevations of the seawall were not fully captured. A review of the LiDAR data showed that the elevations at the wall are approximately 10 feet NAVD88, approximately 2.5 to 3.0 feet higher than the elevation on the DEM. To better represent the seawall, the DEM elevations at the location of the seawall were modified to reflect this elevation. The Harbor Bay Club shoreline elevations were confirmed by reviewing the topographic elevations in the DEM, and no changes were necessary. The original DEM elevations, average LiDAR elevations, modified DEM elevations, and lowest overtopping scenarios for Site B are listed in Table 3.

After the modifications to the DEM representing the Veterans Court area were completed and the inundation maps were updated, the new inundation maps (Attachment A) showed that overtopping of the seawall is not observed until 48 inches of SLR (approximately 10.6 feet NAVD88). However, overtopping still occurs over the Harbor Bay Club shoreline with 36 inches of SLR (approximately 9.6 feet NAVD88), and this inundation impacts the Veterans Court area and Island Drive to the south of Veterans Court.

Figure 5. Site B - Veterans Court Seawall

Figure 6. Site B - Shoreline Adjacent to Harbor Bay Club Looking East at Veterans Court

4.3 Site C - Doolittle Drive at Intersection with Harbor Bay Parkway

Further review of the initial inundation maps and DEM revealed inundation pathways at three sites along Doolittle Drive with 24 inches of SLR. Site C is a section of road built on fill along Doolittle Drive at the intersection of Doolittle Drive and Harbor Bay Parkway. At the intersection, the inundation with 24 inches of SLR occurs via a flow pathway created by a single low-lying elevation on the DEM (see Figure 7). The 2-m resolution DEM had over-smoothed the crown of the road in the intersection, allowing water levels during the MHHW + 24 inch scenario to just exceed the crown and inundate the inland areas behind Doolittle Drive (see Figure 8). The average DEM elevation of the road at the intersection was 8.5 feet NAVD88. To verify the crown elevation of the road, the LiDAR data was overlaid over the DEM. The average LiDAR elevations of the street are approximately 9.0 feet NAVD88, or approximately 0.5 feet higher than the elevations identified on the DEM. The elevations in the DEM were modified to reflect the higher elevation, and the inundation maps were revised. After remapping this focus area using the modified DEM, all sections of Doolittle Drive provide flood protection up to 36 inches of SLR (approximately 9.6 feet NAVD88; See Attachment A). The original DEM elevations, average LiDAR elevations, modified DEM elevations, and lowest overtopping scenarios for Site C are listed in Table 3.

Figure 7. Site C – Inundation Across the Intersection of Doolittle Drive / Harbor Bay Parkway

Note: A low-lying elevation on the DEM at the intersection of Doolittle Drive and Harbor Bay Parkway was found to be a pathway to inundation of inland areas during 24 inches of SLR.

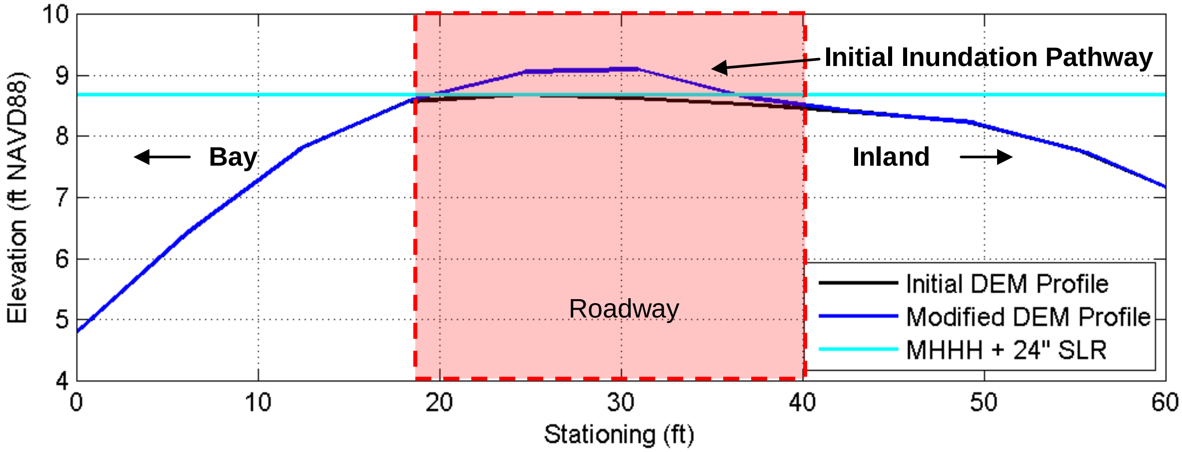

Figure 8. Roadway Cross Section of Intersection at Doolittle Drive and Harbor Bay Parkway

Note: The over-smoothed crown in the original DEM was allowing inundation with 24 inches of SLR (blue line).

4.4 Site D – Doolittle Drive

Site D is a section of Doolittle Drive built on fill approximately 0.2 miles east of the intersection of Doolittle Drive and Harbor Bay Parkway (Figure 9). At Site D, the initial maps showed inundation across Doolittle Drive during 24 inches of SLR via a flow pathway across several low-lying elevations in the DEM, similar to Site C. The 2-m resolution DEM had over-smoothed the highest elevations near the center line of the road allowing water levels during the MHHW + 24 inch scenario to inundate the island in the inundation analysis. The average DEM elevation of the road at this site was 8.5 feet NAVD88 (see Figure 10). The average LiDAR elevations of the street are approximately 9.0 feet NAVD88, so the elevations in the DEM were raised approximately 0.5 feet in this area. The revised inundation mapping for this focus area using the modified DEM shows that all sections of Doolittle Drive provide flood protection until 36 inches of SLR is reached (approximately 9.6 feet NAVD88; See Attachment A). The original DEM elevations, average LiDAR elevations, modified DEM elevations, and lowest overtopping scenarios for Site D are listed in Table 3.

Figure 9. Site D – Doolittle Drive Looking Southeast

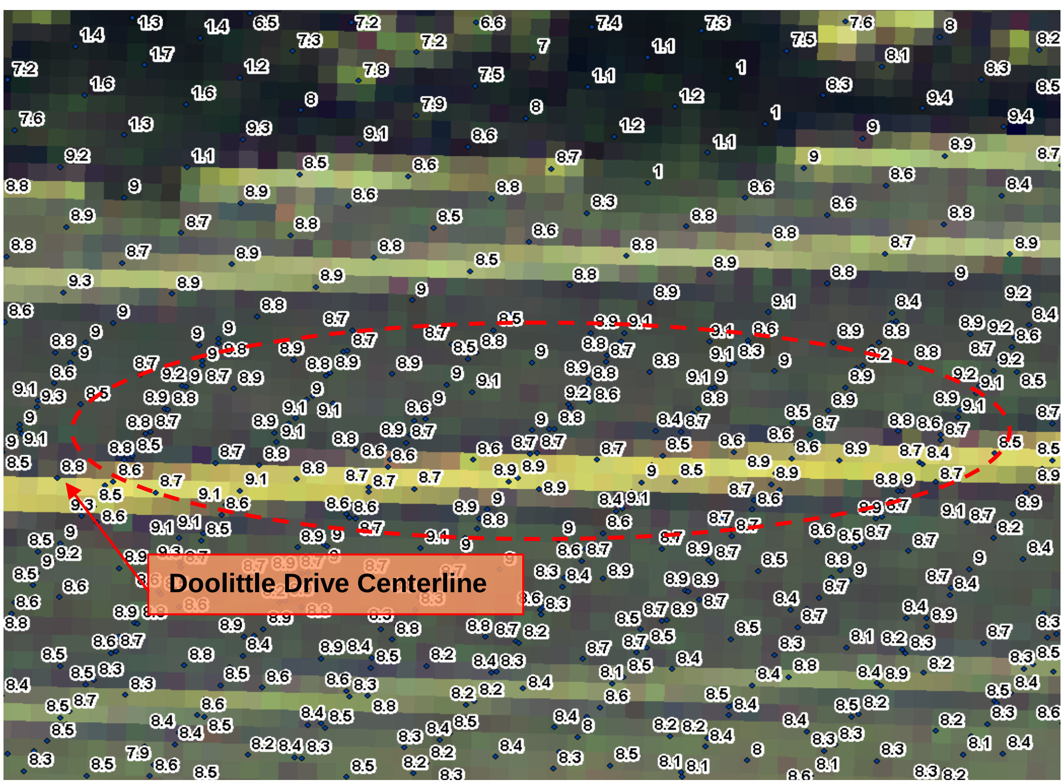

Figure 10. LiDAR Elevations at Site D

Note: The measured LiDAR elevations at the high point in the road are approximately 8.5-9.5 feet NAVD88. The DEM grid cells in the same locations were modified to a minimum elevation of 9 feet NAVD88.

4.5 Site E – Doolittle Drive

Site E on Doolittle Drive is a section of the roadway built on fill, approximately 0.3 miles southeast of the intersection of Doolittle Drive and Harbor Bay Parkway (see Figure 11). At Site E, inundation over Doolittle Drive with 24 inches of SLR was generated via a flow pathway across several low-lying elevations in the DEM, similar to Sites C and D. The 2-m resolution DEM had over-smoothed the highest elevation in the road allowing water levels during the MHHW + 24 inch scenario to inundate inland areas. The average DEM elevation of the road at this site was 8.5 feet NAVD88. The average LiDAR elevations of the street are approximately 9 feet NAVD88, so the elevations in the DEM were raised approximately 0.5 feet in this area. After remapping this focus area using the modified DEM, all sections of Doolittle Drive provide flood protection until 36 inches of SLR (approximately 9.6 feet NAVD88; See Attachment A). Areas further south on Doolittle Drive were also reviewed to confirm the elevations in the DEM, and no changes were warranted. The original DEM elevations, average LiDAR elevations, modified DEM elevations, and lowest overtopping scenarios for Site D are listed in Table 3.

Figure 11. Site E – South Doolittle Drive, Looking Northwest

5. FOCUS AREA VULNERABILITIES

The initial inundation maps for the Alameda County Sea Level Rise Shoreline Vulnerability Assessment indicated that a majority of the Bay Farm Island focus area would be permanently inundated with only 12 inches of SLR. Modifications to the DEM at Sites A-E and subsequent re-analysis verified that system-wide inundation of the focus area will now first occur with 36 inches of SLR (approximately 9.6 feet NAVD88; see Figure 12). In this scenario, overtopping will occur along the low-lying shoreline just west of the Veterans Court seawall in front of the Harbor Bay Club (Site B) and along the northern and eastern sections of Doolittle Drive (Sites C-E). Overtopping at the tide gate wing-wall (Site A) will also occur with 36 inches of SLR. Two additional low areas have been identified on southeast Doolittle Drive (Sites F and G). These sites are low spots on the roadway that can serve as hydraulic connections for floodwaters to reach inland areas with 36 inches of SLR. These sites are also critical pathways to extensive inland inundation at this water level scenario. The areas along the Bay Farm Island shoreline that lead to system-wide inundation during 36 inches of SLR are shown on Figure 12.

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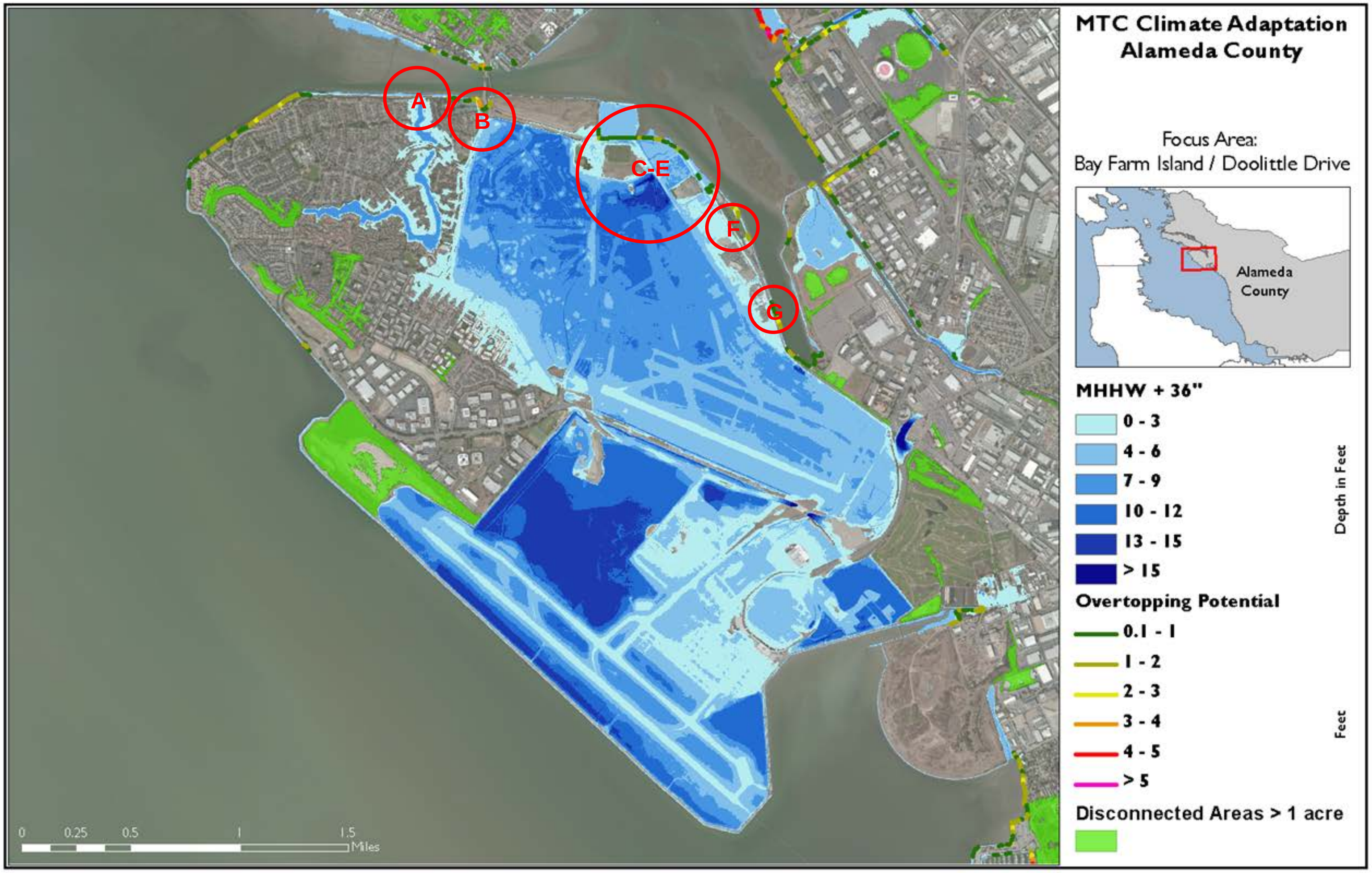

Figure 12. Updated Inundation and Flooding Analysis Using the Modified DEM

Note: System-wide inundation of Bay Farm island is expected at 36 inches of SLR. The tide gate wing-wall (Site A), the Harbor Bay Club shoreline (Site B), and sites along Doolittle Drive (Sites C-G) are the critical inundation pathways in this scenario.

6. TIMING OF POTENTIAL ADAPTATION MEASURES

One of the most important aspects of adaptation planning is determining when and where adaptation measures must be employed in order to prevent inland inundation and flooding. The previous sections have addressed the vulnerable locations that will likely require adaptation strategies. This section focuses on evaluating when, in time, these strategies should be implemented. AECOM examined the timing of adaptation measures from the perspective of maintaining the *existing* level of flood protection in the face of SLR. Although the standard level of design for flood protection features is typically the 100-year (or 1-percent annual chance) flood[6], this level of protection is currently not provided under existing conditions within the Bay Farm Island focus area. The timing of daily inundation, annual flooding events, and less frequent flooding events (in terms of water levels) for the vulnerable sites (A – G) are summarized in Table 4. Under existing conditions, these areas are all expected to be overtopped by a 50-year or greater extreme tide event. Adaptation strategies are therefore required now if this level of protection is to be increased for the 100-year flood event and for SLR over the coming decades.

It should be noted that the extreme tide levels presented in this memorandum do not include the effects of waves at the shoreline which can result in erosion and undermining of existing shoreline protection, or the effects of precipitation-based runoff and current highway drainage were not evaluated which can also result in flooding that will be exacerbated with sea level rise. Bay Farm Island is also largely constructed on fill over former marshlands and the groundwater table is high. Increases in sea level will likely correlate to similar increases in the groundwater table, thereby increasing the potential for flooding and other hazards associated with fill (e.g., saturation and settlement). These compounding circumstances and additional flood risks are not addressed within this study, but they should be considered before implementing adaptation strategies.

Although 36 inches of SLR (approximately 9.6 feet NAVD88) has been identified as the critical threshold for system-wide inundation of the focus area, these areas will also be exposed to flooding by extreme tide events coupled with lower sea level rise scenarios. The cells highlighted in green in Table 2 show the range of potential SLR and storm surge scenarios that could impact Bay Farm Island and could result in a similar overall inundation extent as MHHW + 36 inches of SLR. For example, assets within the inundation zone that will be exposed to daily tidal inundation under the MHHW + 36 inches of SLR scenario could also be exposed to flooding once per year with 24 inches of sea level rise (24 inches of SLR + 1-year extreme tide), or during El Niño[7] conditions with 6 inches of sea level rise (6 inches of SLR + 10-year extreme tide). Based on current NRC (2012) SLR projections, 6 inches of sea level rise is likely to occur by 2030 (NRC 2012).

It should be noted that the previous inundation mapping effort demonstrated that the primary pathway for inundation of Bay Farm Island with 12 inches of SLR was over the Veterans Court seawall (Site B). Although overtopping of this seawall under an temporary extreme tide event is not likely to result

[6] The 100-year flood is typically applied by the Federal Emergency Management Agency (FEMA) for developing Flood Insurance Rate Maps for coastal communities.

[7] The 10-year storm surge elevation is comparable to a typical El Niño winter condition in the Bay.

in wide-scale inundation of Bay Farm Island, overtopping due to long-term SLR could result in significant inundation. Although modifications were made to the DEM to better represent the height of this structure based on orthoimages, LiDAR data, and site visits, it is recommended that the integrity of this structure for providing flood protection be reviewed. Adaptation strategies at Site B may be the highest priority for existing and future flood protection if this structure is deemed insufficient.

Table 4. Timing of Inundation and Flooding

		Timing of Temporary Flooding from Extreme Tides (inches of SLR)						
Site	**Permanent Inundation Scenario (inches of SLR)**	**1-yr**	**2-yr**	**5-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**
A	36	24	18	12	6	6	Existing	Existing
B	36	24	18	12	6	6	Existing	Existing
C-G Doolittle Drive	36	24	18	12	6	6	Existing	Existing
System-wide	**36**	**24**	**18**	**12**	**6**	**6**	**Existing**	**Existing**

Note: Localized areas of shoreline flooding may occur at less extreme tides and the quoted levels of flood protection are based on a high-level examination of the inundation maps and do not represent a rigorous assessment of existing or future flood risk. “Existing” implies that a potential flooding scenario is possible under current conditions with no SLR.

7. POTENTIAL ADAPTATION MEASURES

Bay Farm Island will require multiple adaptation measures to prevent flooding and inundation, because inundation results from concurrent overtopping at several low-lying areas along the shoreline. The strategies suggested below could be implemented to help reduce existing and future flood risks at Sites A, B, and C – G.

7.1 Tide Gate Structure (Site A)

To provide flood protection for the neighborhoods adjacent to the Bay Farm lagoon for SLR greater than 36 inches (or comparable SLR and storm surge scenarios as shown in Table 2, the elevation of the tide gate, associated wing-wall structure, backshore berm behind the wing-wall, and adjacent shoreline should be raised by at least 1 to 2 feet (to approximately 10.5 - 11.5 feet NAVD88). The Bay Farm Lagoon serves as a stormwater retention pond during heavy rainfall events, and the lagoon water levels are typically drawn down before storms to increase the storage capacity. SLR will impact this process so to maintain this function, the entire tide gate structure should be raised. Future adaptation measures should consider the addition of pump systems to draw down the lagoon water levels. The adjacent shorelines should also be improved to provide sufficient freeboard (i.e., additional structure height above the flood hazard water level) above the design water levels (e.g., 36 inches of sea level rise and a 100-year extreme tide level). Additional benefits[8] can be achieved for the neighborhood communities if the structure is designed and constructed to provide protection from the 100-year extreme tide level (including waves) and then accredited by FEMA for providing flood protection.

7.2 Veterans Court Seawall and Harbor Bay Club Shoreline (Site B)

The seawall at Veterans Court should be strengthened and raised to provide a higher level of flood protection. It is recommended that the seawall be raised to meet FEMA standards with sufficient freeboard (i.e., additional structure height above the flood hazard water level) to provide additional protection to accommodate future SLR. However, due to the system-wide inundation that occurs throughout Bay Farm Island with 36 inches of SLR, implementing an adaptation strategy solely for this location will not significantly reduce the overall flood risk to Bay Farm Island. A strategy at this location is needed in tandem with strategies at Site A and Sties C – G.

The shoreline in front of the Harbor Bay Club should also be strengthened and raised by a minimum of 2 feet to approximately 11.0 feet NAVD88 to provide a higher level of flood protection. A higher elevation may be necessary based on freeboard criteria to meet FEMA standards. Additional wave runup analyses are necessary to determine this minimum elevation. An adaptation measure for this shoreline could include retrofitting and raising the existing seawall in addition to raising the berm along the shoreline from the seawall to a location west of the tide gate structure at Site A.

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[8] Flood insurance premiums can be reduced, or eliminated, if the flood protection features remove the structures (e.g., homes) from the FEMA 100-year floodplain.

Alternatively, a living levee[9] could be developed for this location to provide a more natural shoreline aesthetic and valuable habitat transitioning from uplands, to marsh, to mudflat. Depending on the accommodation space available, and the desired level of flood protection, the living levee may require inland land acquisition or encroachment into the bay and existing mudflat areas. The design would also need to accommodate the wave exposure along this shoreline. This adaptation measure will require active long-term management in order to maintain an adequate level of freeboard in response to continually rising sea levels.

7.3 Doolittle Drive (Sites C – G)

Between Sites C and G, the primary flood protection element along Doolittle Drive is the roadway itself. The Bay is located to one side of the roadway, and marshlands and industrial areas are located to the other side. Many of the inland areas are at elevations below the crown of Doolittle Drive. Large sections of Doolittle Drive will be overtopped by water levels of MHHW + 36 inches and higher. Figure 13 shows an elevation profile Doolittle Drive compared to water levels associated with 12-, 24-, 36-, 48-, and 60-inches of SLR. With 24 inches of SLR, the Bay water levels at MHHW will be very near the crown of Doolittle Road, likely compromising its ability to function in its current capacity. With 36 inches of SLR, the overtopping depth along the roadway would be less than 1 foot between Sites C and F. Increasing the existing grade of Doolittle Drive by 1 foot to approximately 10 feet NAVD88, or more, and providing additional shoreline protection features to prevent erosion would provide additional protection for the inland areas from inundation and flooding. However, a strategy that considers the entire length of Doolittle Drive would be more effective at addressing the shoreline vulnerabilities in this area. To provide flood protection up to 48 inches of SLR, or a 100-year storm surge event coupled with 6 inches of SLR, some portions of Doolittle Drive would need to be elevated by 3 feet to approximately 12.0 feet NAVD88. Elevating the roadway should be coupled with shoreline improvements and habitat enhancements such as a living levee, to retain the natural aesthetic and habitat value in this area.

As an alternative to raising the elevation of Doolittle Drive, a levee or seawall could be constructed on the seaward edge of Doolittle Drive. The levee or seawall could be designed and implemented in an adaptable manner that allows the elevation to be increased over time as sea level rise and flood risks increase. However, this strategy would encroach into the bay and require wetland mitigation.

[9] A living levee is a structure which couples multiple benefits, including flood protection and habitat restoration or creation. Typical flood protection levee do not incorporate “living” vegetated elements; whereas a living levee seeks to maximize the inclusion of vegetation in order to create valuable habitats and create habitat corridors which can link critical habitat areas together. Living levees can be found in both coastal and riverine environments.

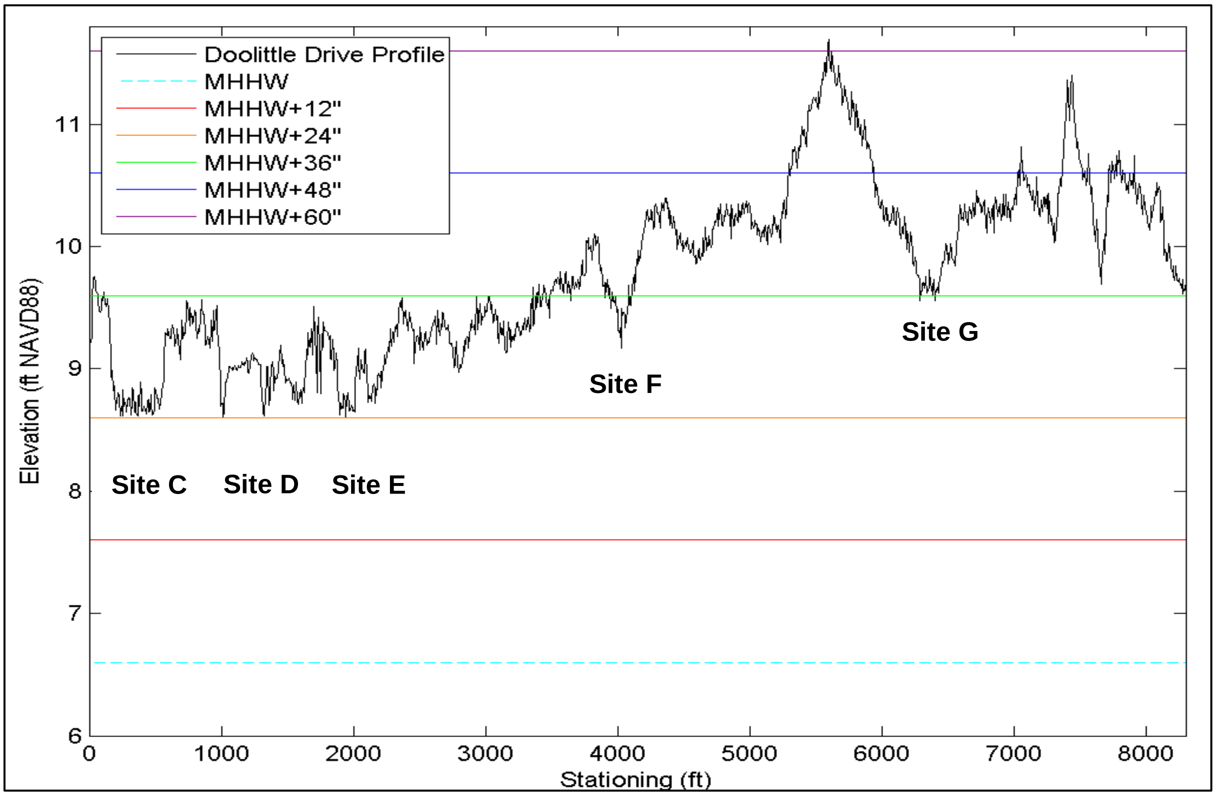

Figure 13. Elevation Profile of Doolittle Drive with Water Level Scenarios

Note: Significant portions of the road are first overtopped with 36 inches of SLR and equivalent flooding scenarios. Each additional foot added to the elevation of the road will increase the flood protection capacity to a successively higher water level. See Figure 12 for site locations.

8. CONCLUSIONS AND NEXT STEPS

Five sites were evaluated in the Bay Farm Island focus area with respect to more detailed SLR exposure in order to confirm the vulnerabilities identified within the previous ART Pilot Project (BCDC et al. 2011). As part of the focus area analysis, the most vulnerable locations were identified, field site visits were performed to confirm the vulnerabilities, and the accuracy of the DEM was verified. The selected sites were distinct areas where an initial assessment of the overtopping potential and inundation maps highlighted possible low-lying areas that led to system-wide inundation of the focus area. The DEM elevations at several locations detailed in this memorandum (Sites A – E) were modified using the source LiDAR data, orthoimages, and site observations as a reference. The revised DEM was used to create new inundation maps and overtopping potential lines so that a more accurate assessment of the critical inundation pathways and flood risk could be evaluated.

Localized shoreline overtopping within the focus area is expected to occur with 24 inches SLR, or may occur under existing conditions with a 5-year extreme tide event. System-wide inundation is expected to occur with 36 inches of SLR – or a lesser amount of SLR coupled with a storm surge scenario. The Bay Farm Island focus area is at risk of flooding under existing conditions with a 50-year extreme tide event. The inundated area includes the Oakland International Airport and the adjacent industrial areas, as well as residential neighborhoods, two elementary schools, and the Chuck Corica Golf Course. To provide a 100-year level of protection under existing conditions, several areas along the shoreline should be raised, strengthened, and improved. Specific adaptation strategies include raising the shoreline in front of the Harbor Bay Club and the Veterans Court seawall to the Bay Farm Lagoon tide gate, raising the Bay Farm Lagoon tide gate and adjacent wing-walls, and raising Doolittle Road.

Shoreline erosion, degradation of coastal protection structures, land subsidence, increasing groundwater levels, and runoff-driven flooding from rainfall were not considered as part of this focus study assessment. The cumulative impacts of rainfall runoff events occurring during periods of extreme tide levels were also not considered in this analysis. However, given the low-lying nature of Bay Farm Island, and that fact that it is constructed primarily of fill over former marshlands, these additional risk factors should be seriously considered and evaluated when developing and implementing adaptation strategies – particularly strategies that focus on solely on providing improved shoreline protection. Although shoreline structures and strategies can prevent or inhibit overtopping and inland inundation of Bay waters, rising groundwater levels and rainfall-driven flooding could result in compounded flood risk for this area. Areas developed with fill will be particularly susceptible to groundwater intrusion and subsidence. An increase in soil saturation, coupled with increased rainfall and runoff, will further exacerbate flooding. Existing inland drainage systems will become less effective with higher groundwater levels and they may become completely ineffective with higher levels of SLR. Though outside the scope of our current study, evaluation of these mechanisms is recommended as a next step.

9. REFERENCES

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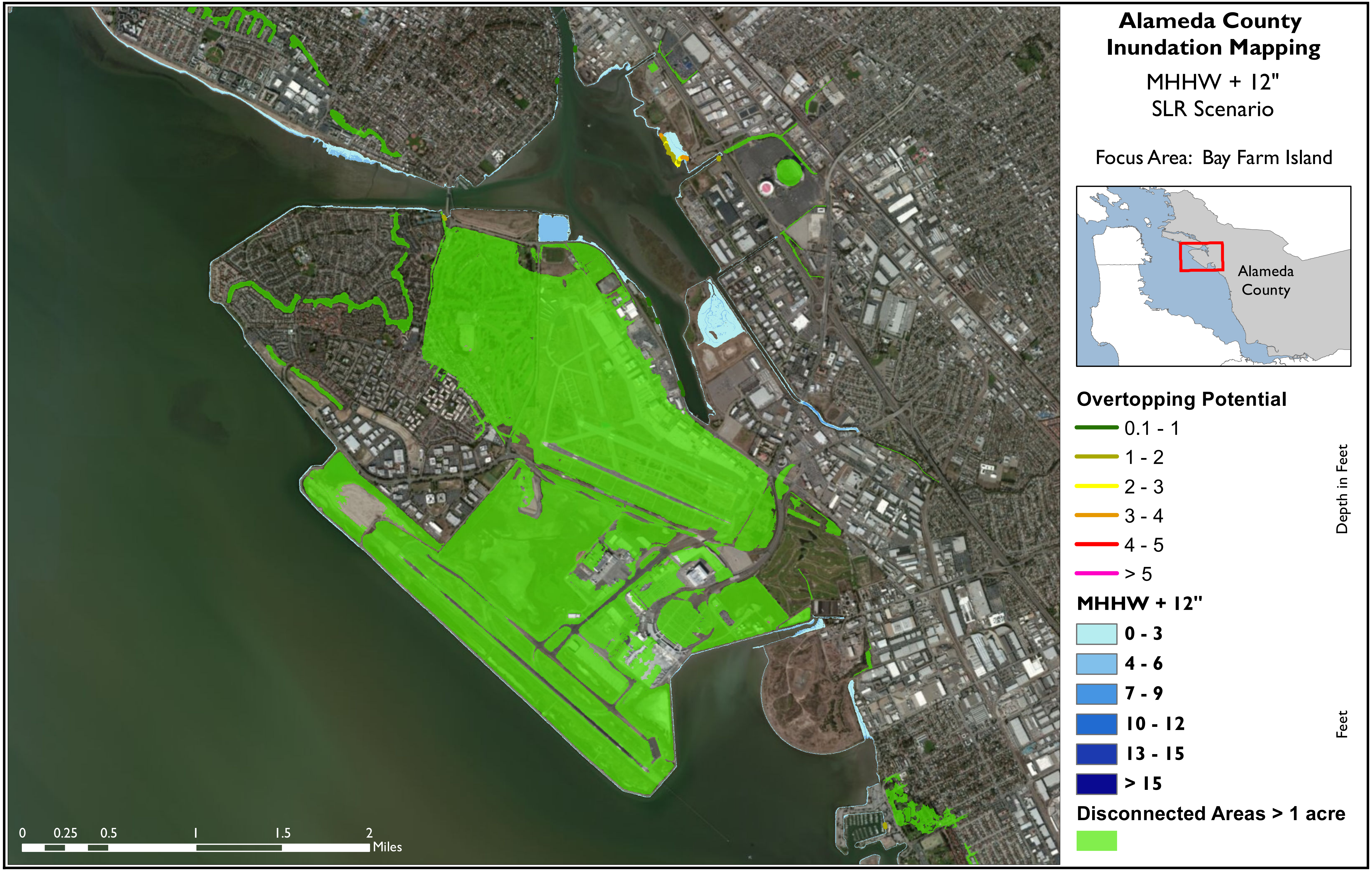
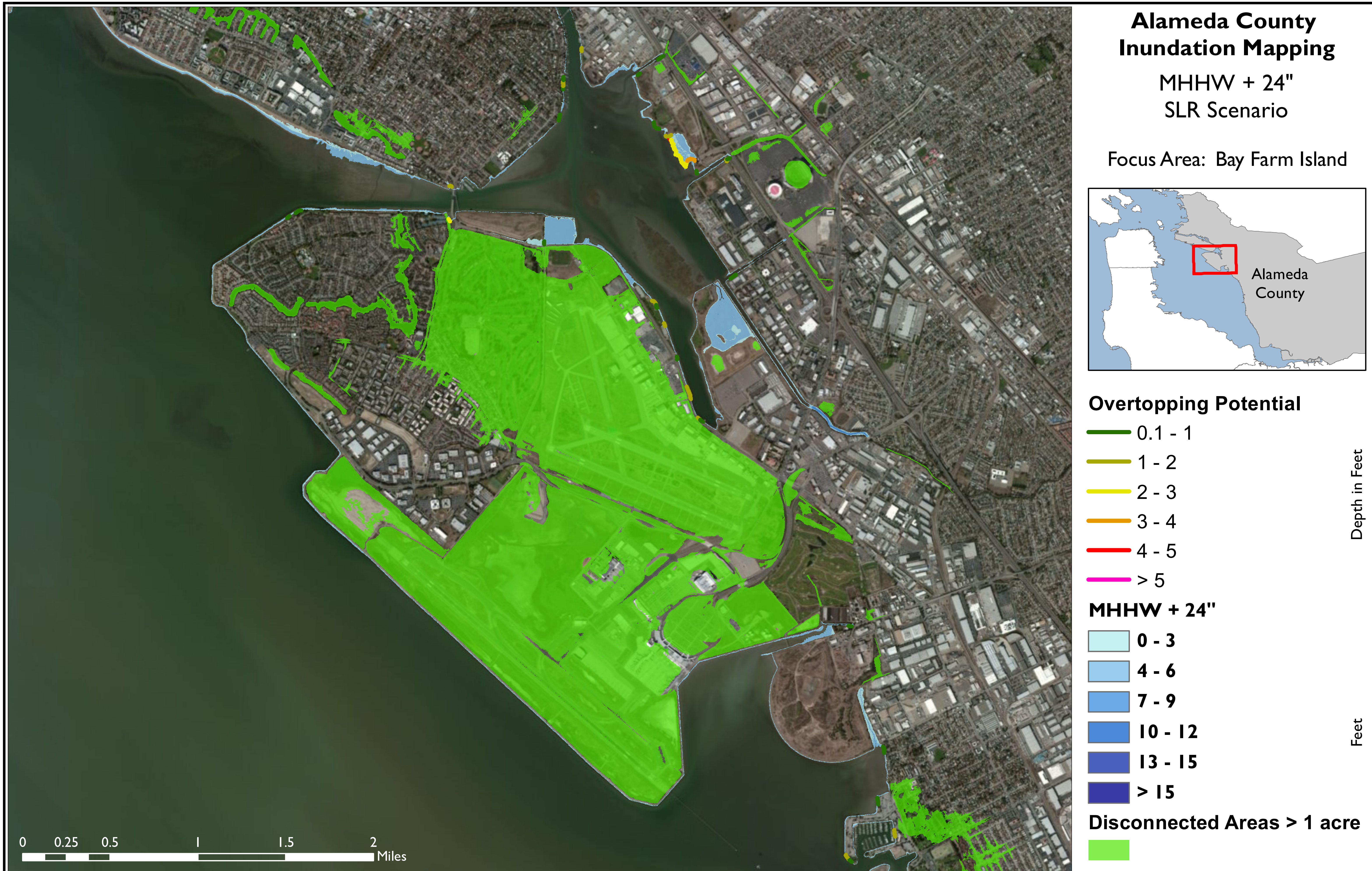
Attachment A – Focus Area Inundation Maps



Alameda County
Inundation Mapping
MHHW + 12"
SLR Scenario
Focus Area: Bay Farm Island
Alameda County
Overtopping Potential
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Depth in Feet
MHHW + 12"
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Feet
Disconnected Areas > 1 acre
0
0.25
0.5
1
1.5
2
Miles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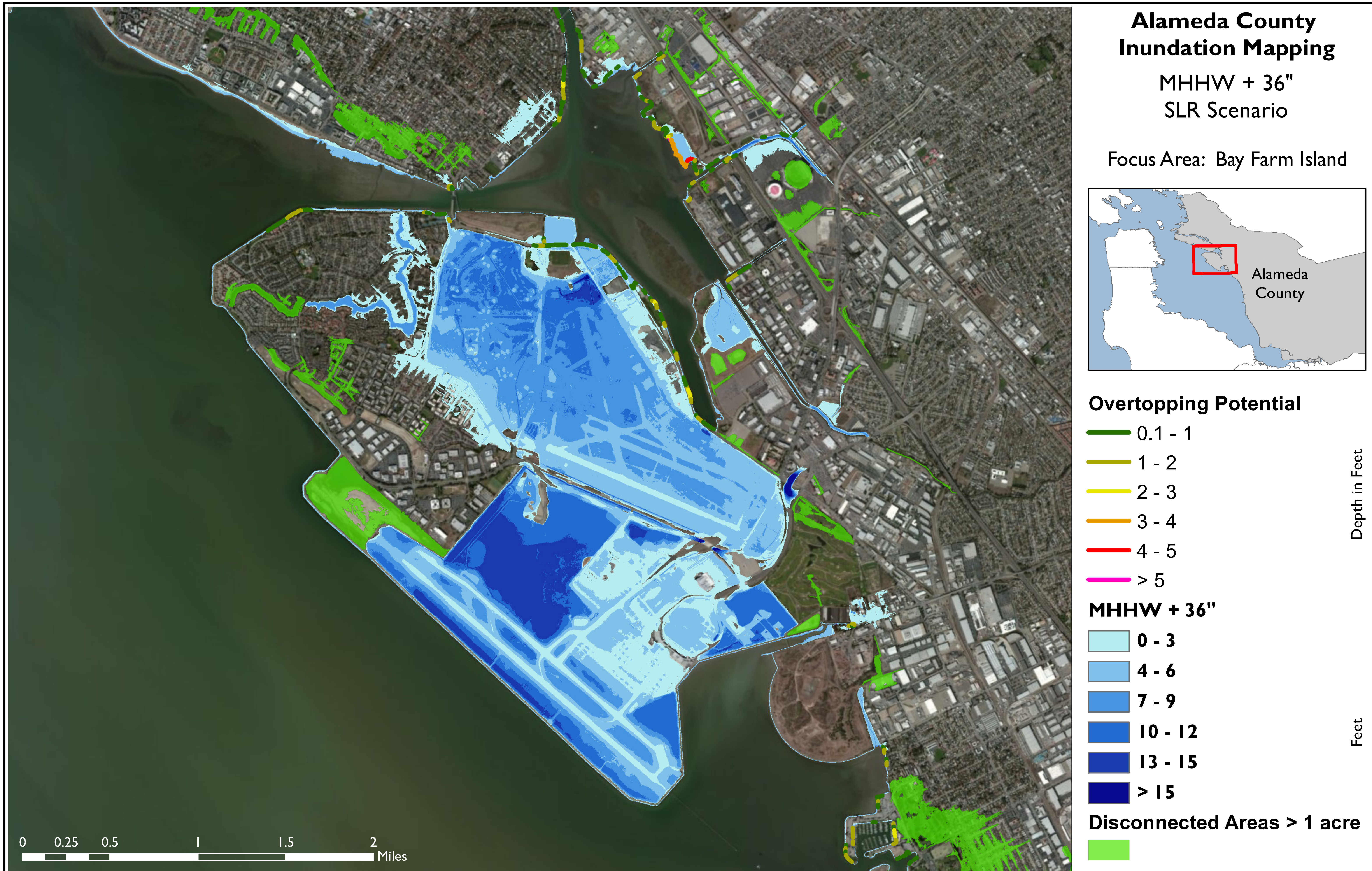
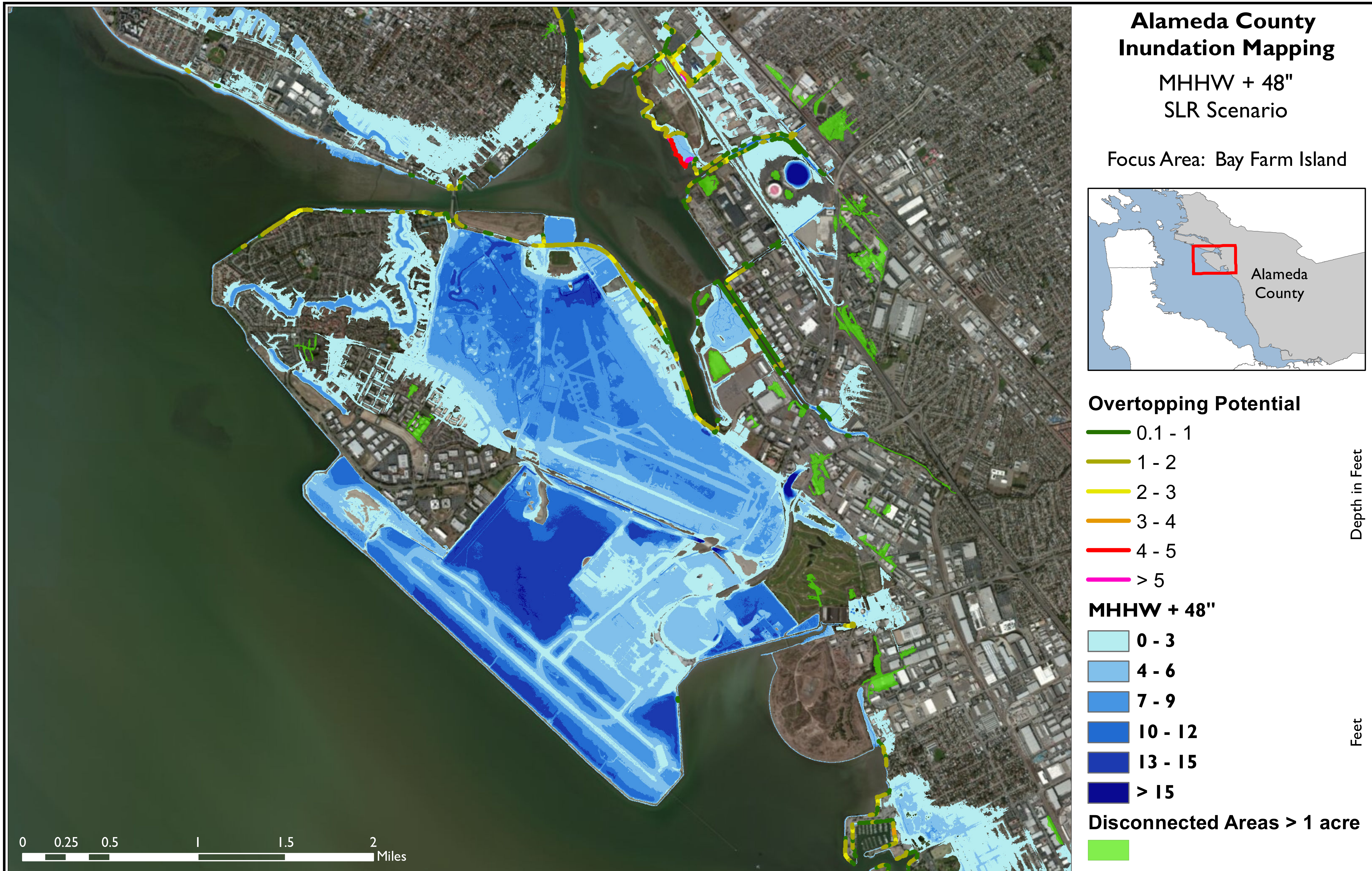
Inundation Mapping
MHHW + 24"
SLR Scenario
Focus Area: Bay Farm Island
Alameda
County
Overtopping Potential
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Depth in Feet
MHHW + 24"
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Feet
Disconnected Areas > 1 acre
0
0.25
0.5
1
1.5
2
Miles


Alameda County
Inundation Mapping
MHHW + 36"
SLR Scenario
Focus Area: Bay Farm Island
Alameda
County
Overtopping Potential
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Depth in Feet
MHHW + 36"
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Feet
Disconnected Areas > 1 acre
0
0.25
0.5
1
1.5
2
Miles



Alameda County
Inundation Mapping
MHHW + 48"
SLR Scenario
Focus Area: Bay Farm Island
Alameda County
Overtopping Potential
0.1 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Depth in Feet
MHHW + 48"
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Feet
Disconnected Areas > 1 acre
0
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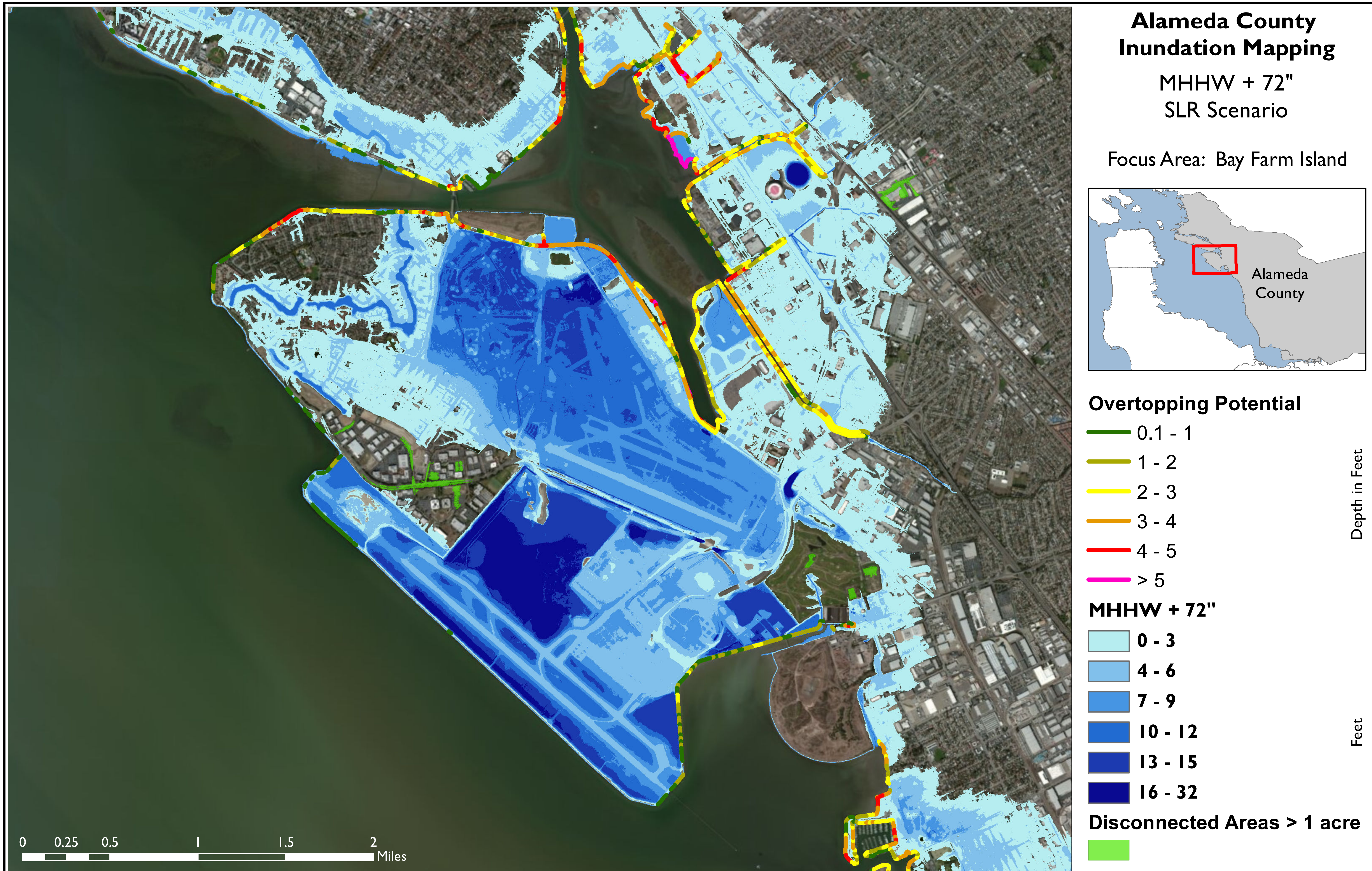
0.5
1
1.5
2
Miles


Alameda County
Inundation Mapping
MHHW + 72"
SLR Scenario
Focus Area: Bay Farm Island
Alameda
County
Overtopping Potential
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3 - 4
4 - 5
> 5
Depth in Feet
MHHW + 72"
0 - 3
4 - 6
7 - 9
10 - 12
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16 - 32
Feet
Disconnected Areas > 1 acre
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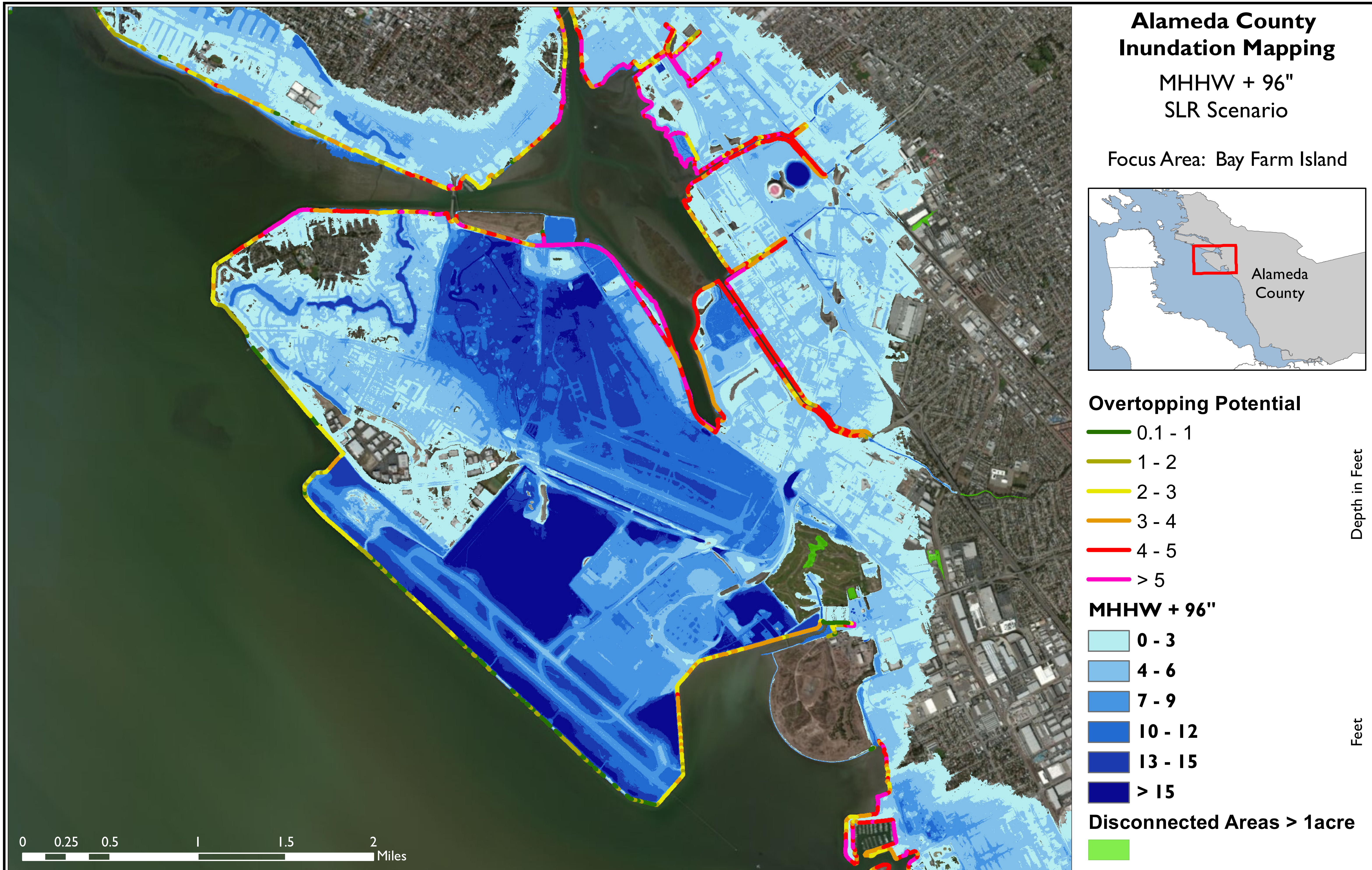
0.5
1
1.5
2
Miles



Alameda County
Inundation Mapping
MHHW + 96"
SLR Scenario
Focus Area: Bay Farm Island
Alameda County
Overtopping Potential
0.1 - 1
1 - 2
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3 - 4
4 - 5
> 5
Depth in Feet
MHHW + 96"
0 - 3
4 - 6
7 - 9
10 - 12
13 - 15
> 15
Feet
Disconnected Areas > 1acre
0
0.25
0.5
1
1.5
2
Miles

Attachment B – Bay Farm Island Focus Area Site Visit Photos

Attachment B - Site Visit Photos (March 05 and March 07, 2014)

Bay Farm Island Focus Area– Looking East along Harbor Bay Club Shoreline (Site B)

Bay Farm Island Focus Area– Looking East along Harbor Bay Club Shoreline (Site B)

Bay Farm Island Focus Area– Doolittle Drive Shoreline Looking North

Bay Farm Island Focus Area– Doolittle Drive Shoreline Looking North (Site G)

Appendix C

Asset Vulnerabilities and Consequences by Focus Area and Compendium of Strategies

ASSET VULNERABILITIES AND CONSEQUENCES BY FOCUS AREA

FOCUS AREA: BAY BRIDGE FOCUS AREA

ASSET 1: BURMA ROAD ELECTRICAL SUBSTATION

VULNERABILITIES

Informational Vulnerabilities (INFO)

INFO1: There is lack of detailed, easily accessible, and well-coordinated information about the ownership, location, and condition of energy infrastructure, including this electrical substation, which is needed for site- and asset-specific vulnerability and risk assessments.

Governance Vulnerabilities (GOV)

GOV1: PG&E owns the substation, which provides power to the City of Oakland, and is governed by the CPUC and FERC. This could make it difficult for Oakland and other agencies that rely on the substation for power (e.g. Caltrans) to get detailed information or engage in shared planning, decision making, or funding to prepare for flood events.

Physical Vulnerabilities (PHYS)

PHYS1: Components of substation are sensitive to water and saltwater and could be damaged by water/saltwater exposure.

PHYS2: The substation is located in an area with high seismic susceptibility and/or liquefaction potential. Higher groundwater conditions could increase the liquefaction potential and subject the substation to more damage than expected during a seismic event.

Functional Vulnerabilities (FUNC)

FUNC1: Businesses, residences, the Port of Oakland, wastewater and stormwater facilities, critical transportation infrastructure (lights, signals, communications), and rail (BART), rely on power to maintain continuity of operations. Depending on the connection of this substation to the overall power grid, operations of all these services (and related services) would be impacted if the substation is disrupted by storm events and sea level rise.

CONSEQUENCES

Equity
Disruption of the substation would cause loss of power to businesses, residents, and critical infrastructure including West Oakland, which has been identified by MTC as a Community of Concern.

Environment
If the substation is not protected from flooding, hazardous materials/substances could be released into the environment. Additionally, if power is disrupted to businesses and operations (especially industrial uses), components or equipment which include hazardous materials/substances may release these

substances into the environment if they cannot function.

Economy

Disruption of power to the transportation and transit system would disrupt commuter movement and the ability of people to get to their jobs. Businesses may be non-operational without power and would lose revenue. Additionally, employees would not be able to work at these businesses.

ASSET 2: EBMUD DE-CHLORINATION AND DISCHARGE FACILITY

VULNERABILITIES

Informational Vulnerabilities (INFO)

None

Governance Vulnerabilities (GOV)

GOV1: EBMUD owns the asset and provides service to communities in the northern part of Alameda County and a small portion of western Contra Costa County. Each community owns and operates its own wastewater collection system that conveys wastewater to the EBMUD interceptor system. Due to this interdependency, many assets will be affected by the temporary disruption or permanent loss of, or adaptation responses for, other assets that are owned and operated by different departments or entirely separate agencies.

GOV2: All of the wastewater treatment providers in Alameda County maintain emergency response plans covering emergency operating procedures and back-up equipment and parts. All treatment providers (except Livermore) share emergency repair assistance and equipment through mutual aid arrangements. The number of different plans could make planning for sea level rise and storm events difficult if there is no coordination.

GOV3: Many agencies including the US EPA, the California Regional Water Quality Control Board, BCDC, and others have regulatory authority over the de-chlorination and discharge facilities that could make planning for sea level rise and storm events difficult if there is no coordination.

GOV4: Final effluent from the treatment plant is de-chlorinated and then discharged to the Bay in accordance with National pollution Discharge Elimination System (NPDES) permit. Disruption of either of these facilities, which sit on the shoreline, would have significant consequences. Upgrades, retrofits or reengineering will require coordination with a number of state, regional and federal regulatory agencies that could make planning for sea level rise and storm events difficult.

Physical Vulnerabilities (PHYS)

PHYS1: The facility is located in the 100-year floodplain and is susceptible to damage from flooding and storm events.

PHYS2: The facility is located in an area with high seismic susceptibility and/or liquefaction potential which could increase if groundwater levels rise.

PHYS3: The facility is accessible by only one road. Disruption of the road access to the facility due to flooding would restrict chemical deliveries and the ability for EBMUD staff to sample to confirm chlorine removal from the effluent.

Functional Vulnerabilities (FUNC)

FUNC1: Disruption of the de-chlorination facility could result in the discharge of chlorinated secondary-treated wastewater to the Bay.

FUNC2: There are no redundant assets within the EBMUD system that could replace the function of the de-chlorination and discharge facilities, and there is no capacity for EBMUD to connect to other systems. Disruption of these two facilities would have significant impacts on the ability of the entire system to function in a manner meeting customer and regulatory requirements.

CONSEQUENCES

Equity
Employees of the facility would not be able to work if it or the road leading to the facility is flooded/non-operational.

Environment
If the facility is flooded and/or non-operational, hazardous waste and pollutants could be released into the environment. This could compromise residents and businesses in the surrounding communities, habitats, water quality, etc.

Economy
Businesses and industries that rely on the wastewater treatment plant might not be able to operate.

ASSET 3: EBMUD MAIN WASTEWATER TREATMENT PLANT

VULNERABILITIES

Informational Vulnerabilities (INFO)
None

Governance Vulnerabilities (GOV)

GOV1: EBMUD owns the asset and provides service to communities in the northern part of Alameda County and a small portion of western Contra Costa County. Each community owns and operates its own wastewater collection system that conveys wastewater to the EBMUD interceptor system. Due to this interdependency, many assets will be affected by the temporary disruption or permanent loss of, or adaptation responses for, other assets that are owned and operated by different departments or entirely separate agencies.

GOV2: The wastewater treatment plant relies on flood protection by land not owned and operated by EBMUD (e.g. the tidal marsh and I-80E). This could make planning for sea level rise and storm events difficult if there is no coordination.

GOV3: All of the wastewater treatment providers in Alameda County maintain emergency response plans covering emergency operating procedures and back-up equipment and parts. All treatment providers (except Livermore) share emergency repair assistance and equipment through mutual aid arrangements. The number of different plans could make planning for sea level rise and storm events difficult if there is no coordination.

GOV4: US EPA and the California Regional Water Quality Control Board have regulatory authority over the wastewater treatment plant discharges that could make planning for sea level rise and storm events difficult if there are regulatory requirements that conflict with managing for sea level rise and storm events.

GOV5: Treated wastewater effluent is discharged from the treatment plant to the Bay in accordance with National Pollutant Discharge Elimination System (NPDES) permit. Current and future NPDES permit requirements could make planning for sea level rise and storm events difficult if there is not good coordination on water quality and climate resilience decision making.

Physical Vulnerabilities (PHYS)

PHYS1: Deteriorated local sanitary sewer systems and improper storm drain connections allow rainwater to enter into the sewer system, causing wet weather flows that can overload the treatment plant and create a need for wet weather treatment facilities that are located along the shoreline often in locations that make these facilities themselves vulnerable.

PHYS2: The wastewater treatment plant has below-grade infrastructure with electrical and mechanical equipment and could be susceptible to damage by water or salinity if flooded.

PHYS3: If the EBMUD main wastewater treatment plant was flooding during a storm events there could be significant damage to sensitive electrical and mechanical equipment that are not waterproof or corrosion resistant.

PHYS4: The cathodic protection systems used to protect underground pipelines and other related equipment or facilities could be overwhelmed by an elevated water table or saltwater intrusion.

Functional Vulnerabilities (FUNC)

FUNC1: Flooding could affect the plant's gravity-fed treatment processes and require increased reliance on pumping. Flooding could also increase flows beyond capacity, resulting in operational failures, overflows, and backups.

FUNC2: Equipment with electrical components such as motors, instrumentation, and motor control centers could cease to operate if they were to get wet.

FUNC3: Wastewater treatment systems are large, expensive, and complex. While there is equipment and process redundancy in the treatment plant, there is limited ability to divert flows if the entire plant is compromised, making them highly vulnerable to disruption from sea level rise and storm events.

CONSEQUENCES

Equity
If the wastewater treatment plant is flooded and/or non-operational, it would affect all the municipalities, businesses, and residents that rely on the system; they may not be able to use their sewage, plumbing, and water systems. Additionally, employees of the plant would not be able to work.

Environment
If the wastewater treatment plant is flooded and/or non-operational, hazardous waste and pollutants could be released into the environment. This could compromise residents and businesses in the surrounding communities, habitats, water quality, etc.

Economy
Businesses and industries that rely on the wastewater treatment plant might not be able to operate.

ASSET 4: EMERYVILLE CRESCENT (WITHIN THE MCLAUGHLIN EASTSHORE STATE PARK)

VULNERABILITIES

Informational Vulnerabilities (INFO)

INFO1: Sea level rise will increase the depth, duration, and frequency that tidal marshes are flooded. To counteract this flooding, marshes can build upward or move landward depending on the available sediment supply and adjacent land use, respectively. While future sediment supply is unknowable, site-specific information on current available sediment supply to Emeryville Crescent would improve our understanding of its resilience to sea level rise.

Governance Vulnerabilities (GOV)

GOV1: EBRPD manages the park including the Emeryville Crescent under agreement with State Parks, and five different agencies (BCDC, DFW, USACE, RWQBC, and EPA) have regulatory authority over the asset. This complex regulatory framework could be difficult when funding, planning and implementing projects that address sea level rise and storm events.

Physical Vulnerabilities (PHYS)

PHYS2: The Emeryville Crescent is mostly mid marsh, but habitat change models predict the marsh will downshift over the century and ultimately convert to mudflat. The trajectory of this change will depend on the rate of sea level rise and the supply of available sediment to support vertical accretion.

PHYS3: The Emeryville Crescent is bordered by I-80 and there is no space for the marsh to move landward to avoid being squeezed between a rising Bay and urban development.

Functional Vulnerabilities (FUNC)

FUNC1: Birds and wildlife that use the Emeryville Crescent may be displaced by shifts in habitat (from mid to low marsh, or low marsh to mudflat) and by more frequent or permanent inundation. These changes may force them to forage and nest closer to people and infrastructure, such as Powell Street and I-80, and will likely impact their survivorship.

CONSEQUENCES

Equity
Local and regional community members would not be able to watch birds and wildlife that use the Emeryville Crescent as it downshifts overtime, and as marsh habitats covert to mudflat.

Environment
Birds and wildlife might be displaced or forced to use less suitable areas close to local roads and highways due to loss of habitat.

Economy
The Emeryville Crescent provides natural flood protection for I-80 and the surrounding development, which would be diminished if the marsh converts to mudflat.

ASSET 5: PORT OF OAKLAND SEAPORT OPERATIONS

VULNERABILITIES

Informational Vulnerabilities (INFO)

INFO1: There is lack of detailed, easily accessible and well-coordinated infrastructure information about the transportation assets that serve the seaport (roads/rail) that is necessary to assess the vulnerability and risk to seaport operations.

Governance Vulnerabilities (GOV)

GOV1: The Port of Oakland owns the seaport, but there are several different operators that operate the terminals, as well as goods movement entities that use the seaport. The number of operators and entities could make it difficult to coordinate planning efforts.

GOV2: The seaport links to other modes, including rail and the highway system, and is surrounded by other land uses. These other modes and land uses are managed by other agencies (e.g. Caltrans, UPRR, the City of Oakland) and could make it difficult to coordinate maintenance, planning, decision making or funding efforts.

Physical Vulnerabilities (PHYS)

PHYS1: The seaport is located in an area with high seismic susceptibility and/or liquefaction potential. Past ground acceleration from the 1989 Loma Prieta earthquake caused widespread liquefaction and sand boils in several terminals, resulting in up to one foot of settlement and distress to backland pavement, utilities, and small buildings. Increased groundwater levels due to sea level rise could increase this risk.

PHYS2: Infrastructure located under the wharves at the seaport may be increasingly vulnerable to high water levels and wave erosion during storm events, which can disrupt asset function, cause scour, require additional maintenance, and potentially shorten asset life span.

Functional Vulnerabilities (FUNC)

FUNC1: Freight and goods movement carriers that utilize the seaport would all be impacted if operations were disrupted by storm event or sea level rise.

FUNC2: There are few alternative truck routes and they have limited additional capacity to accommodate re-routed trucks. If significant roadways or nodes were disrupted that serve seaport operations, and re-routing was required, this would result in heavy congestion that could overwhelm the region’s roadways and interstates.

FUNC3: The regional rail system that serves the seaport lacks redundancy, and has a fixed and linear nature that makes it highly vulnerable to disruption. Damage at any point in the rail system can disrupt goods movement system-wide, causing significant economic effects at the seaport and region wide.

FUNC4 (T8). The seaport is linked to the greater region by only one or two access-ways and could become isolated during a significant flood or storm event.

FUNC5 (T9). The seaport exports a significant amount of perishable goods, such as agricultural products.

Sea level rise and storm events could delay and disrupt the movement and delivery of these goods and there are not regional alternative locations from which these perishable items can be exported.

FUNC6 (T10). Other seaport facilities in the region do not have sufficient capacity to handle additional cargo if operations at the Port of Oakland seaport were disrupted by sea level rise or storm events.

CONSEQUENCES

Equity
Seaport employees would not be able to work if the seaport is disrupted by storm events or sea level rise. Additionally, the seaport exports goods and necessities that the region relies on.

Environment
If the seaport is flooded, hazardous substances/materials could be released into the environment.

Economy
The seaport is a gateway for the region's imports and exports; if operations are disrupted, these activities would cease and the region (including businesses, industries, and residents that rely on the goods that come in / go out of the seaport) would be severely impacted.

FOCUS AREA: COLISEUM FOCUS AREA

ASSET 1: OAKLAND COLISEUM AMTRAK STATION

VULNERABILITIES

Informational Vulnerabilities (INFO):

INFO1: There is a lack of detailed, easily accessible, and well-coordinated information about the Oakland Coliseum Amtrak Station components, which are owned and managed by different entities. For example, information about the condition and elevation of the station, parking lot, and ramp leading to a pedestrian bridge may be available to the City of Oakland but is not shared with Capitol Corridor Joint Powers Authority (CCJPA) who manages the intercity passenger rail service.

INFO2: Detailed information on the type, condition and elevation of the railroad may be available from Union Pacific Rail Road (UP) who own and operate the rail track and right of way (ROW), however the accessibility, ease of use, and quality of this data is unknown as UP does not have a practice of openly sharing information on its assets.

INFO3: The City of Oakland and/or the Alameda County Water Conservation and Flood Control District (ACWCFCD) may have information on the capacity and condition of the stormwater and flood control systems that are in place near the station, however this information is not publically available and can be challenging to obtain.

Governance Vulnerabilities (GOV):

GOV1: The number and relationships of public agencies and private entities that own and operate the station, rolling stock, rail track and ROW, and the passenger rail service complicates planning and implementing improvements or use changes. The Coliseum Amtrak station, the parking lot, and the ramp leading to the walkway between the Coliseum BART station and the Coliseum are owned and maintained by the City of Oakland. The Capitol Corridor intercity passenger rail service is managed by the Capitol Corridor Joint Powers Authority (CCJPA), while Union Pacific owns the railroad and the right of way (ROW), which includes the station platform.

GOV2: CCJPA does not have control over the surrounding land, road, or transit that provides access to the station or services or those that provide flooding protection. Ensuring that access to the station remains viable and that current levels of flood protection are maintained will require cooperation between CCJPA, City of Oakland, Alameda County Flood Control and Water Conservation District (ACFCWCD). Any changes to the station would need to comply with local land use plans, codes and standards, while changes to the boarding platform, which is in the UP ROW and subject to a lease agreement, would need to be coordinated with UP and CCJPA and could be more challenging.

GOV3: There is an Alameda County Flood Control and Water Conservation District (ACFCWCD) pump station exists near the end of the cul-de-sac on 73rd Avenue, which is the road that provides access to the station and the adjacent parking lot. ACFCWCD coordinates with the City of Oakland on stormwater and flood control management, but has no direct relationship with CCJPA. Disruption of this pump station, which sits below grade, could cause local flooding that disrupts passenger or maintenance crew access to the station and parking lot.

Physical Vulnerabilities (PHYS):

PHYS1: The station was built as slab-on-grade of materials not intended to withstand flooding of any duration. Mechanical and electrical equipment (e.g. ticket machines, lighting, electronic notification system) that are essential to the safe operation of the station will be damaged by exposure to water and/or salinity.

PHYS2: The safe operation of the station relies on utilities that are below-grade. Specifically, the underground pump station managed by ACWCFCD and utilities owned by PG&E, Comcast, and AT&T that are located in the area along San Leandro Street from 75th to 66th Avenue including 73rd Avenue. Electrical and mechanical equipment are generally not water or saltwater proof, even if located below-grade, and rising groundwater or overland flooding could disrupt these elements.

PHYS3: The station is located in an area with high liquefaction potential if there was a seismic event. Neither the station nor the rail track will be able to withstand high levels of liquefaction, which could be of increasing risk as groundwater levels rise in this area.

Functional Vulnerabilities (FUNC):

FUNC1: Station is served by a free parking lot and there are few alternative locations to park and leave cars aside from limited on-street parking. If 73rd Avenue is closed due to flooding, pedestrians can still access the station via the pedestrian overhead bridge from the Coliseum BART station. However, parking for those using the passenger rail service may be limited at the Coliseum BART station.

FUNC2: The function of the station will be affected by a disruption to commercial power supplies as the electronic notification system, lighting, and monitoring cameras that are part of the operations of this station will be disrupted, making the station unsafe for users at night and inconvenient in general due to lack of train information and status updates.

FUNC3: Service to and from the station would be affected by a disruption to commercial power supplies, as the signal system is critical to the safe operation of the rail service. Although the signal system has battery backups that can last a few hours, and then there are protocols in place for manual signally by railroad staff, these are only short-term solutions.

FUNC4: If the rail track in the vicinity of the Coliseum is flooded or damaged the intercity passenger rail service will be disrupted and the Coliseum Amtrak station will not be in service. An alternative bus bridge service could be set up to get passengers around the disrupted rail track and station; however this is only a short-term solution.

FUNC5: Due to the linear connectivity of rail track, a disruption to any rail segment within the Capitol Corridor would impact passenger service. There is no realistic alternative route for the service, or in fact for goods movement, if this segment of rail track is damaged or disrupted.

FUNC6: There are no alternative rail transit options providing intercity service from San Jose to Sacramento, and the state highway I-880 that could provide an alternative route for car or bus service is vulnerable to the same sea level rise and storm event impacts as this segment of rail track.

CONSEQUENCES

Equity
None

Environment
None

Economy
Loss of the Capitol Corridor intercity passenger rail service would affect commuters that use the service to access jobs, goods or services in the cities and metro areas of the Bay Area and Sacramento regions.

- Loss of the Coliseum Station would not interrupt Capitol Corridor rail service, however disruption of this station would affect passengers that use this station, and would be a significant impediment to using the rail system to travel to events held at the Coliseum venues.
- Disruption of the rail track in the vicinity of the Coliseum Amtrak station would not only significantly affect passenger service, it would also disrupt freight operations and affect goods movement as there are not alterative rail alignments along this portion of the East Bay shoreline. Disruption of goods movement, and in particular perishable goods moving to or from the Port of Oakland Seaport, would have significant economic impacts.

ASSET 2: SAN LEANDRO STREET

VULNERABILITIES

Governance Vulnerabilities (GOV)

GOV1: San Leandro St. is owned and operated by the City of Oakland. Oakland is on an 85-year repaving schedule (standard is 25), and the city's streets score low (56/100) on MTC's Pavement Condition Index (Bay Area average is 66/100).

Functional Vulnerabilities (FUNC)

FUNC1: San Leandro Street serves several transit lines: AC Transit Lines 98, 73, and 45 all run on San Leandro St. past Coliseum BART.

FUNC2: San Leandro Street is part of a network of roads; if other roads are disrupted, traffic may be re-routed to San Leandro Street, which may not have sufficient capacity. In addition, San Leandro St. provides access to BART and Amtrak (Coliseum Station) and I-880. An interruption of any of these elements of the network could have an effect on other elements.

CONSEQUENCES

Equity
San Leandro St. connects the road network to Coliseum BART and Amtrak trains so any disruptions would disproportionately affect transit-dependent households.

Environment
None

Economy
Disruptions in access to the Coliseum BART and Amtrak stations (on San Leandro St.) would negatively affect commuter movement and goods movement and could lead to cascading economic effects within the region.

ASSET 3: OAKLAND COLISEUM COMPLEX

VULNERABILITIES

Governance Vulnerabilities (GOV)

GOV1: The Coliseum is jointly owned by a JPA that consists of the City of Oakland and Alameda County (Oakland-Alameda County Coliseum Authority). It is managed by AEG (Anschutz Entertainment Group). The Coliseum is the home to the Oakland A's and Oakland Raiders, and the Arena is home to the Golden State Warriors. The Arena also hosts concerts and events. The many interests could complicate changes necessary to adapt to sea level rise.

Physical Vulnerabilities (PHYS)

PHYS1: The playing surface of the stadium is below grade and actually below current sea level, along with everything on the clubhouse level (showers, offices, visitor training room and storage areas). It already experiences problems with sewage backups, as well as drainage problems when it rains heavily.

CONSEQUENCES

Equity
The Coliseum provides entertainment to the region, and is the foundation of the transportation hub (BART and Amtrak Stations, bus stops). Its disruption could eventually affect how transportation is organized in the city, which could affect adjacent communities that rely on those transportation services.

Environment
None

Economy
Coliseum complex brings in revenue to the City and County through taxes (though there has been at least one instance where a team refused to pay taxes) and rent, and provides employment. Its disruption or destruction would reduce or eliminate this revenue stream.

ASSET 4: MARTIN LUTHER KING JR. REGIONAL SHORELINE / ARROWHEAD MARSH

VULNERABILITIES

Informational Vulnerabilities (INFO)

INFO1: There is a database with the condition and elevation of Bay Trail available to owners and managers. However, this database is not geo-referenced or very high quality. There is no publicly available database with, for example, the owners and managers of Bay Trail segments.

Governance Vulnerabilities (GOV)

GOV1: MLK Jr. Shoreline and Arrowhead Marsh are owned by the Port of Oakland and managed by EBRPD. Many sections of Bay Trail, managed by EBRPD, are on levees owned by ACFCWCD, with a land use agreement between the agencies. Because of these multiple owners and managers, coordination will be required in order to make changes to adapt to sea level rise.

GOV2: Many agencies have regulatory authority over MLK Jr. Shoreline: USACE San Francisco District (Section 404 permit); USFWS and NOAA (Section 7 consultations for the endangered species act); RWQCB (Section 401 certification); some projects require permits from BCDC or a review under CEQA/NEPA. The many agencies involved and permits required means that a lengthy process may be required to make changes to adapt to sea level rise.

Physical Vulnerabilities (PHYS)

PHYS1: Although the Bay Trail is paved in MLK Shoreline, some of it is on top of poorly maintained levees that are vulnerable to erosion, which undercuts the trail.

PHYS2: Some of the levees may have fiber optic cables or tide gates located under, within, or adjacent to them. This could complicate any work necessary to repair or protect against the effects of sea level rise.

Functional Vulnerabilities (FUNC)

FUNC1: The Bay Trail connects over 300 miles of trails. If one part of the system is not operational, some of the overall functionality could suffer. In particular, this section is an important north-south commuting corridor both on the mainland and on Bay Farm Island.

FUNC2: Arrowhead Marsh is mapped as mid marsh with very little high tide refugia. It is projected to downshift to low marsh by midcentury and to mudflat by end-of-century. The federally endangered clapper rail relies on the high-tide refugia that currently exist; in the future, the marsh may not be able to serve this function for this species and others.

FUNC3: Damon Slough seasonal wetlands will be increasingly inundated by rising sea level and over time downshift to marsh habitat. Vertical accretion modeling indicates that Damon Marsh will not keep pace with sea level rise through this century. Its downshifting trajectory depends on the sea level rise rate and sediment supply. The wetlands currently provide habitat for the federally endangered clapper rail. This function could diminish with sea level rise.

CONSEQUENCES

Equity
MLK Jr. Shoreline provides commuting options, recreation, access to the shoreline, and wildlife viewing; these opportunities are free to the public, including several underserved / low-income communities in the vicinity. The shoreline also provides school programs and volunteer programs. If the shoreline is eroded or flooded, or the Bay Trail undercut, these recreational and program opportunities would be lost for the local communities.

Economy
MLK Jr. Shoreline provides $4.8M in recreation value per year, which would be reduced or lost as sea level rise changes and diminishes shoreline and habitat. It also provides commuting options via the Bay Trail that could be lost or disrupted.

Environment
The Shoreline provides habitat for at least one endangered species, which could be lost due to sea level rise. In addition, various types of ecosystems (high marsh, mid marsh, seasonal wetlands) could be lost as sea level rise causes them to downshift to low marsh and mudflat.

FOCUS AREA: HAYWARD FOCUS AREA

ASSET 1: BAY TRAIL

VULNERABILITIES

Informational Vulnerabilities (INFO)
None

Governance Vulnerabilities (GOV)

GOV1: Repairs of the Bay Trail are difficult to implement due to the trail's location on levees and along marshes due to permitting constraints, e.g., threatened and endangered species and Bay fill. Storm events and sea level rise will likely increase the need for repairs because higher water levels increase levee erosion.

GOV2: EBRPD has no regular Bay Trail preventative maintenance program, such that minor damage may be hard to repair in a timely, low-cost manner and result in serious disruptions.

GOV3: EBRPD does not have plans for how to improve or maintain the Bay Trail in the Hayward Regional Shoreline in the face of future storm events and sea level rise.

GOV4: EBRPD manages all of the Bay Trail within the Hayward Shoreline Area but the pedestrian bridge over CA-92 is owned by Caltrans and the Bay Trail south of the bridge is owned by CADFW. This shared responsibility may complicate future planning and maintenance efforts.

Physical Vulnerabilities (PHYS)

PHYS1: Since the Bay Trail is located on levees, which are vulnerable to erosion and overtopping, the trails will erode or flood as the levees are overtopped or eroded.

Functional Vulnerabilities (FUNC)

FUNC1: The stretch of Bay Trail in the Hayward Shoreline Area has no nearby alternative routes so disruption to any part of the trail disrupts the entire stretch.

FUNC2: The Bay Trail pedestrian bridge over CA-92 cannot be easily moved or rerouted.

CONSEQUENCES

Equity
The Bay Trail provides free shoreline recreation to all residents of the Bay area. If the Bay Trail through Hayward is disrupted or permanently damaged, residents will lose recreation opportunities. Bay Trail also provides shoreline access for limited-mobility residents; this access is particularly vulnerable to sea level rise because even temporary flooding or mud and debris on trails can preclude limited-mobility visitors from recreating on the shoreline. If flooding disconnects the Bay Trail, negative effects would extend to neighboring Bay Trail segments.

Environment
The Bay Trail makes shoreline access possible for millions of Bay Area residents. This exposure to the Bay, wildlife, and natural areas helps build support for environmental protection and restoration. If the Bay Trail is disrupted or damaged, this capacity will be diminished.

Economy
The Bay Trail in Hayward provides over $490,000 in recreation benefits each year to the local and regional economy. Long term disruption or permanent closure would reduce these benefits.

ASSET 2: COMMERCIAL AND INDUSTRIAL LAND USE

VULNERABILITIES

Informational Vulnerabilities (INFO)

INFO1: Emergency response planners from the City of Hayward do not have access to detailed information on the specific needs and operations of facilities within the focus area. Without this information it is difficult to prepare for flood events and help business owners mitigate their own risks.

Governance Vulnerabilities (GOV)

GOV1: Often commercial and industrial properties are owned by one individual or organization and rented by another. Therefore the individual tenants do not have control over the level of protection or resilience of the property, and may not be aware of the potential future flood risk.

Physical Vulnerabilities (PHYS)

PHYS1: Portions of the industrial park along the flood control channels are low-lying and have experienced flooding. Sea level rise will increase flood risk in these low-lying areas unless there are improvements or upgrades to the flood control system to store increased flood flows.

Functional Vulnerabilities (FUNC)

FUNC1: Businesses like warehouses, office parks, and factories all rely on roads, power, and water and wastewater treatment. If these services are disrupted by storm events and sea level rise, day-to-day operations of the industrial park could be disrupted even if specific properties are not flooded.

CONSEQUENCES

Equity

The commercial and industrial land uses in the study area employ a significant number of people. If the businesses are damaged or disrupted by sea level rise impacts, these jobs may leave Hayward or disappear entirely.

Environment

If industrial and commercial businesses are flooded, hazardous materials may be released into the environment and damage marsh habitat, water quality, and species.

Economy

The commercial and industrial land uses in the study area pay taxes to Hayward and generate revenue for the area. If the businesses are damaged or disrupted by sea level rise impacts, these economic benefits could be diminished or lost.

ASSET 3: EDEN LANDING ECOLOGICAL RESERVE

VULNERABILITIES

Informational Vulnerabilities (INFO)

INFO1: None - extensive monitoring including of current available sediment supply to Baumberg Track is being conducted as part of the South Bay Salt Pond Restoration Project. Sediment supply is not an issue for managed ponds.

Governance Vulnerabilities (GOV)

GOV1: Eden Landing has dual objectives of wildlife habitat and flood protection. Levees, berms and ponds provide flood protection benefits to Hayward and any restoration must preserve the same level of flood protection. This requirement constrains restoration around the ponds and marshes because both goals are so heavily regulated (e.g. USACE Section 404 permit, Endangered Species Act Section 7 consultation with USFWS and NOAA, BCDC permit, RWQCB Section 401 certification).

GOV2: The second phase of restoration work at Eden Landing, including adaptive management for sea level rise, does not have a clear funding source.

Physical Vulnerabilities (PHYS)

PHYS1: Threatened and endangered species within Eden Landing managed ponds require particular water levels and sea level rise will put pressure on the existing system of levees, water control structures, and drainage operations, e.g., ponds may become more reliant on pumping as opposed to gravity-fed configurations. The adaptive management plan includes a framework to evaluate whether managed ponds should be abandoned and converted to other (likely tidal) habitat types, depending on their elevation, location in the Bay, and the need for specific habitat types from wildlife populations at risk. Areas allowed to transition to tidal marsh would still need to maintain their intertidal position and depending on their elevation capital, could be vulnerable to downshifting.

PHYS2: Baumberg Tract is fully tidal and mostly low marsh, which means that it is especially vulnerable to increases in flood depth, duration, and frequency. Habitat change models predict the marsh will downshift over the century (trajectory depends on sea level rise rate and sediment supply).

PHYS3: Baumberg Tract is backed by industrial/residential development. Unless this land use changes, there is not space for the marsh to move landward and avoid being squeezed between a rising Bay and steep inboard levee.

Functional Vulnerabilities (FUNC)

FUNC1: Eden Landing provides extensive wildlife habitat and flood protection benefits to inland industrial/residential development that will not be sustained if the managed ponds are overtopped or tidal marsh systems transition to mudflats or fringing marshes.

CONSEQUENCES

Equity

People enjoy the views of the managed ponds and Baumberg Tract from the Bay Trail and the loss of these areas would reduce recreation value.

Environment

Eden Landing provides both tidal marsh habitat and pond habitat for nesting shorebirds and waterfowl. It is an important migratory stopover for Pacific Flyway species. Storm event flooding makes tidal marsh species more vulnerable to predation and can reduce reproductive success if nests are flooded (Nur et al. 2012). Furthermore, downshifting habitat means marshes will be flooded more often, exacerbating population stresses, until conversion of marsh to mudflat results in complete loss of tidal marsh species. Loss of control of water levels in managed ponds would result in loss of species that use these areas, including threatened and endangered nesting species like snowy plover.

Economy

Eden Landing is the first line of defense against coastal flooding of the industrial/residential development and these natural flood protection benefits were explicitly considered during restoration design. If Eden Landing and its natural flood protection benefits were lost, existing structural shorelines would not be sufficient to protect against FEMA 100-year flows and people and business in the area would be affected.

ASSET 4: HAYWARD SHORELINE INTERPRETIVE CENTER

VULNERABILITIES

Informational Vulnerabilities (INFO)
None

Governance Vulnerabilities (GOV)
None

Physical Vulnerabilities (PHYS)

PHYS1: HSIC is located in an area vulnerable to increased flooding due to storm events and sea level rise. While the HSIC is a raised structure, the floor of the building was built at 12.3 feet (NAVD 88) so there is minimal clearance above high water levels such as King Tides (approximately 9 feet).

PHYS2: HSIC is not constructed of waterproof materials and contains mechanical equipment, such as aquariums and electronics such as computers and power supplies, that would be damaged by even short-duration flooding.

Functional Vulnerabilities (FUNC)
FUNC1: Since the HSIC depends on trails and marshes for educational interpretation purposes, which are vulnerable to erosion, flooding, and associated habitat changes, the HSIC is functionally vulnerable.

CONSEQUENCES

Equity
HSIC reaches over 9,000 students and adults each year through their educational programs. If the HSIC is temporarily or permanently closed or relocated, these people will lose recreation and educational services.

Environment
HSIC helps Bay Area residents develop a personal connection with the Bay, marsh habitat, and endangered species. If HSIC closes or relocated, people may be less willing to fund and/or support habitat protection and restoration.

Economy
HSIC generates over $60,000/year in revenue for HARD and employs nine people. If HSIC is temporarily or permanently closed, this revenue and employment would be diminished or list.

ASSET 5: OLIVER SALT PONDS

VULNERABILITIES

Informational Vulnerabilities (INFO)
None - sediment supply is not an issue for managed ponds.

Governance Vulnerabilities (GOV)

GOV1: HARD manages the Oliver Salt Ponds (voluntarily) for snowy plover and does not have a clear funding source to raise the inboard levees that currently flood from extreme tides through the HARD Marsh and into some of the Oliver Salt Ponds. The system is managed passively due to this lack of funding.

GOV2: The Oliver Salt Ponds have a management plan, which was last updated in 2002 when the system was enhanced. However, the plan and enhancements did not account for sea level rise and this lack of planning and oversight may limit HARD's ability to maintain the ponds as sea level rises.

Physical Vulnerabilities (PHYS)

PHYS1: Oliver Salt Ponds are managed ponds and sea level rise will increase the frequency of overtopping outboard and inboard levees. While the outboard levees were repaired and raised in 2012 (following the 2005 - 2006 New Year's Eve storm), overtopping of the inboard levees floods some (but not all) of the ponds and compromises the snowy plover nesting season.

Functional Vulnerabilities (FUNC)

FUNC1: Oliver Salt Ponds provides educational value for the Hayward Shoreline Interpretive Center and some wildlife habitat (snowy plover numbers have been down in recent years, perhaps in part due to superior habitat in Eden Landing). These benefits would be lost or diminished if sea level rise overtops the ponds.

CONSEQUENCES

Equity
The Oliver Salt Ponds provide educational value for the Hayward Shoreline Interpretive Center and the loss of the ponds would result in changes to the educational program of the Hayward Shoreline Interpretive Center.

Environment
The Oliver Salt Ponds provide habitat for waterfowl and shorebirds, including species migrating on the Pacific Flyway. They also provide marginal habitat for federally threatened snowy plover. The consequence of losing the Oliver Salt Ponds may be minor because there is habitat available for these species in Eden Landing.

Economy
None

AGENCY SPECIFIC VULNERABILITIES AND CONSEQUENCES - CALTRANS

ASSET 1: MULTIPLE

VULNERABILITIES

Informational Vulnerabilities (INFO)

INFO1: Most planning-grade data (such as storm drain and bridge crossing locations, for example) is generally readily available, accessible, and most of it exists in a geospatial format that can easily be shared internally and externally.

INFO2: Design and survey-grade data (such as structure elevation information) can be challenging to access and use. This type of data tends to be created on a project-by-project basis, and therefore the information is available in a project file, it is not easily accessible through a system-wide, centralized database.

INFO3: Caltrans has a Document Retrieval System (DRS) which is a searchable repository the Department's project plans. However, these as-built and layout plan sheets are stored in PDF format and are not geo-referenced. The repository can be searched by location (county, route, and post-mile); however, this only brings up a list of all the projects, big and small, that have occurred in that location over time. The user must then wade through a list of hundreds of projects at any particular location, and within each project folder, a list of hundreds of more plan sheets, to find the desired as-built file. The user can also search by project number to find plan sheets for a single, specific project, but most people working outside of Project Management, or without institutional knowledge, would have a difficult time identifying projects in this fashion.

INFO4: Access to the Caltrans Document Retrieval System (DRS) is not available to the public, so a request for detailed design data would have to be made either through the Public Affairs office, or through the Office of Program/Project Management.

Governance Vulnerabilities (GOV)

GOV1: Institutional knowledge housed within certain staff or departments outside of Planning can make it challenging to understand vulnerability and risk. Project managers and engineering staff are primarily funded to support the delivery of transportation improvement projects, with less of a formal mechanism to provide input on planning efforts like adaptation planning projects.

GOV2: Maintenance costs for this asset are fairly typical and not excessive; however overall agency resources are not adequate to achieve all of the maintenance needed and therefore how funds are expended have to be prioritized.

GOV3: Regulatory oversight can be lengthy, in particular obtaining a biological opinion if necessary. A Biological Opinion can take up to 18 months. To obtain all the necessary permits that could be required for significant work in this area could take 2-3 years, e.g., from San Francisco Bay Permit (BCDC), Section 404 (USACE), 401 Certification (RWQCB), Biological Opinion (USFWS), CESA compliance (CDFW).

GOV4: Caltrans operated drainage systems ultimately discharge to Alameda County Water Conservation and Flood Control District (ACWCFCD) or city stormwater and flood control assets. Both ACWCFCD and the city have limited financial resources for repairs, upgrades, and retrofits of flood control and stormwater infrastructure. Although the Caltrans hydrology unit works with ACWCFCD and the City of Oakland to coordinate on drainage and flood control how the two agencies would share planning or funding for future upgrades is unknown. The capacity of this system to continue functioning as the Bay rises is unknown.

Physical Vulnerabilities (PHYS)

PHYS1: A consistent supply of power is necessary to provide lighting for safe night driving on interstates and state routes and to maintain operability of Changeable Management Signs (CMS).

ASSET 2: 1-880 7TH STREET TO THE TOLL PLAZA

VULNERABILITIES

Governance Vulnerabilities (GOV)

GOV5: Agency coordination is required to maintain the connections between the interstate and local streets and roads. For example, the City of Oakland maintains the main connectors to I-880 from 7th Street and Grand Avenue. Caltrans does maintain some local roads (overcrossings) through maintenance agreements with the City of Oakland.

Physical Vulnerabilities (PHYS)

PHYS2: Saltwater intrusion and a rising groundwater table may cause corrosion of the reinforcing in concrete structures that support the elevated portion of this roadway *(this vulnerability needs to be double checked to determine how the footings were constructed).*

PHYS3: A rising groundwater table could damage the at-grade pavement structural section of this section of I-880 near 7th street, in particular if the roadbed is constantly saturated. Groundwater can also damage the landscaping and cause major dewatering problems for future construction.

PHYS4: There are five separate tributary drainage areas along I-880 between 7th Street and the Toll Plaza with storm drain systems to drain water from the freeway. The capacity of these systems to continue functioning as the Bay rises is unknown.

Functional Vulnerabilities (FUNC)

FUNC1: There is limited redundancy for car or bus (AC Transit) commuters that rely on this segment of I-880 to access the Bay Bridge or I-80 West. Alternative routes such as I-980 to I-580 or West Grand to the toll plaza have limited additional capacity and would not be able to provide the same level of service necessary if this segment of I-880 was disrupted.

FUNC2: There are very limited alternatives to re-route goods movement if this section of I-880 was disrupted, in particular because this segment provides the main point of access for truck traffic to/from the Port of Oakland Seaport. Re-routing truck traffic can be challenging due to road use restrictions, e.g. I-580, I-980 and local streets and roads have truck restrictions.

CONSEQUENCES

Equity

This segment of I-880 provides access to the shoreline for recreation, for example via 7th Street to Middle Harbor Shoreline Park, and via 7th St/Maritime St/Burma Rd. to the future Gateway Park. The loss of this segment of I-880 or its connection to 7th Street will have consequences on local and regional shoreline recreation.

Environment

None

Economy

This segment of I-880 provides access to major local employment centers along the corridor, including the Port of Oakland Seaport, and a connection for commuters between Oakland and San Francisco. Disruption of this segment of I-880 could have significant impact on worker access to local and regional jobs.

This segment of I-880 is the major truck route though the Bay Area, e.g., from San Jose to Sacramento. Disruption of this segment of I-880 would have significant impacts on regional, intra-state and inter-state goods movements, as there are truck restrictions on most other alternate routes.

ASSET 3: I-880 FROM COLISEUM WAY TO 98TH AVENUE

VULNERABILITIES

Informational Vulnerabilities (INFO)

INFO5: The capacity of the Damon Slough and Elmhurst Creek Bridges to contain future extreme water levels is unknown and further studies are needed to understand how these bridges may or may not be of adequate capacity as sea level and groundwater rises.

Governance Vulnerabilities (GOV)

GOV5: There are billboards in the Right-of-Way of this segment of I-880 that are subject to a 2005 Landscape Maintenance Agreement with the Oakland-Alameda Coliseum. Changes to the billboards would require coordination and is subject to the current agreement.

Physical Vulnerabilities (PHYS)

PHYS2: Saltwater intrusion and a rising groundwater table may cause corrosion of the reinforcing in concrete structures that support the elevated portion of this roadway and the Damon Slough and Elmhurst Bridge crossings.

PHYS3: Increases in wind, wave or tidal energy s the Bay rises could increase the scour at the abutments of the Damon Slough and Elmhurst Bridges and erosion in the flood control channel both up and downstream of the bridges.

PHYS4: A rising groundwater table could impact this section of I-880 in particular because it is all at-grade and pavement structural section could be damaged if the roadbed is constantly saturated. Groundwater can also damage the landscaping and cause major dewatering problems for future construction.

PHYS5: There are three separate tributary drainage areas along I-880 between the 66th Avenue and 98th Avenue with Caltrans operated storm drain systems to drain water from the freeway. Although most of the inlets, outfalls, discharge points, junction boxes, and storm pipes are listed as in good condition, the capacity of this system to continue functioning as the Bay rises is unknown. These systems ultimately discharge to Alameda County and City of Oakland drainage assets.

PHYS6: The Damon Slough Bridge has been noted to have water levels close to the road deck at extremely high tide indicating that it is likely already undersized. Sea level rise will exacerbate this issue as the bridge will likely be under capacity more frequently at high tide.

Functional Vulnerabilities (FUNC)

FUNC1: This segment of I-880 serves the Oakland International Airport, in particular via the Hegenberger and 98th street exits. There are no adequate alternative routes to access the airport as the only option would be local streets and roads that do not have similar capacity.

FUNC2: There is limited redundancy for commuters that rely on this segment of I-880. Alternative routes include local streets and frontage roads that cannot accommodate the same capacity as this section of I-880. The use of I-580 as an alternative would require a significant rerouting of traffic and there is not the capacity to provide the same level service.

FUNC3: There are many transit operators that serve a corridor parallel to I-880 (AC Transit, Capital Corridor, and BART); however, it is unlikely these transit providers could provide commuters an adequate alternative, both in terms of capacity and desired route, for more than a short duration disruption.

FUNC4: There are very limited alternatives to re-route goods movement if this section of I-880 was disrupted, in particular because this segment provides the main point of access for truck traffic to/from the Port of Oakland Seaport. Re-routing truck traffic can be challenging due to road use restrictions, e.g. I-580, I-980 and local streets and roads have truck restrictions.

CONSEQUENCES

Equity

This segment of I-880 provides local and regional access to shoreline recreation at the Martin Luther King Regional Shoreline. Disruption of this section of I-880 would have consequence on the public's access to this fairly lengthy shoreline park.

This segment of I-880 serves the Fruitvale and East Oakland neighborhoods, which are identified as MTC Communities of Concern.

Environment

The loss of capacity of the Damon Slough and Elmhurst Creek Bridges could cause higher channel water levels for longer periods of time that could stress existing habitat, cause bank and channel erosion, and deposit trash/pollutants on the banks and adjacent uplands.

Economy

This segment of I-880 provides access to major local employment centers along the corridor, including the Port of Oakland Seaport and Oakland International Airport, and a connection for commuters between the East Bay and San Francisco Peninsula, and along the East Bay shoreline. Disruption of this segment of I-880 could have significant impact on worker access to local and regional jobs.

This segment of I-880 is the major truck route though the Bay Area, e.g., from San Jose to Sacramento. Disruption of this segment of I-880 would have significant impacts on regional, intra-state and inter-state goods movements, as there are truck restrictions on most other alternate routes.

ASSET 4: 1-80 / I-580 POWELL ST. TO TOLL PLAZA

VULNERABILITIES

Governance Vulnerabilities (GOV)

GOV5: Inter-agency coordination is required for the operations and maintenance of this segment of I-880, the San Francisco-Oakland Bay Bridge (SFOBB) toll plaza, and the bike path. For example, Caltrans maintains the facilities within their Right-of-Way while the local jurisdictions are responsible for adjacent local streets. There are Maintenance Agreements with the cities of Oakland and Emeryville for the maintenance of local streets that connect to the interstate, as well as for the bike path leading to SFOBB, and a Co-op Agreement between Caltrans and BATA outlining toll plaza operations responsibilities. Changes to this segment of I-880, the toll plaza, and the bike paths will require inter-agency coordination, decision making, and potentially funding.

Physical Vulnerabilities (PHYS)

PHYS2: Saltwater intrusion and a rising groundwater table may cause corrosion of the reinforcing in concrete structures that support the elevated portion of this roadway and the Damon Slough and Elmhurst Bridge crossings.

PHYS3: Saltwater intrusion and a rising groundwater table may cause corrosion problems for metal pipes, reinforcing in concrete structures, and pump equipment that are necessary to maintain operations at the toll plaza and this segment of I-80/I-580. A high groundwater table can damage at-grade pavement structural sections if they are constantly saturated, ruin landscaping, and cause major dewatering problems for future construction.

PHYS4: There are two above-ground fuel storage tanks located at the Burma Road Maintenance Station. One tank contains 5,000 gallons of E85 fuel and the other tank contains 3,000 gallons of bio-diesel fuel and 6,000 gallons of gasoline. While these tanks are permanent and not mobile they could be vulnerable to damage or failure if not constructed to withstand wind, wave or tidal energy. Damage to these tanks would result in the diesel and gasoline stored in them to enter the Bay.

PHYS5: Infrastructure serving the toll plaza and this segment of I-80/I-580 are potentially susceptible to salt water intrusion/corrosion, for example the pump house at the toll plaza and the emergency waste-water overflow structure that is buried under and near the edge of the Temescal Creek overcrossing structure.

PHYS6: There are five separate tributary drainage areas along I-80/I-580 between the Toll Plaza and Powell Street with storm drain systems to drain water from the freeway. The capacity of this system to continue functioning as the Bay rises is unknown.

Functional Vulnerabilities (FUNC)

FUNC1: There are limited alternative routes for commuters that rely on this segment of I-80/I-580. Local streets and frontage roads do not provide adequate redundancy as they cannot accommodate the same traffic capacity.

FUNC2: There are no local or convenient alternatives for cars, trucks or busses to cross the Bay if the SFOBB toll plaza is damaged or inoperable as the next closest crossing is 22 miles south.

FUNC3: This segment of I-80/I-580 carries traffic towards San Francisco and points north and south, as well as AC Transit Transbay Buses. There are alternative transit providers serving this corridor parallel to I-80/I-580 (AC Transit local buses, Capital Corridor, and BART) that could provide some redundancy for commuters, however, it is unlikely these transit providers could provide commuters an adequate alternative, both in terms of capacity and desired route, for more than a short duration disruption.

FUNC4: There is limited for goods movement that relies on this section of I-80 and I-580, especially for goods bound for, or leaving, San Francisco and the peninsula and the east bay.

FUNC4: There are very limited alternatives to re-route goods movement if the toll plaza or this section of I-80/I-580 was disrupted, especially for goods movement between the San Francisco peninsula and the East Bay and for goods bound to/from the Port of Oakland Seaport. Re-routing truck traffic can be challenging due to road use restrictions, e.g. I-580, I-980 and local streets and roads have truck restrictions.

CONSEQUENCES

Equity

This segment of I-80/I-580 serves drivers and transit riders in MTC Communities of Concern in West and North Oakland.

This section of I-80/I-580 provides access to the bicycle and pedestrian path along the newly constructed eastern span of the SFOBB and will likely provide access to the planned Gateway Park area.

Environment
The loss of capacity of the Temescal Creek Bridge could cause backwater conditions in the channel, causing higher water levels for longer periods of time that could stress existing habitat, cause bank and channel erosion, and cause trash/pollutants to collect on the banks and adjacent uplands.

Fuel tanks at the SFOBB toll plaza could pose a risk to local water quality and habitat if they were to topple or failed during a storm event (these tanks are elevated and store fuel for Caltrans maintenance vehicles).

Economy
This section of I-80 and I-580 provides access to major employment centers along this corridor, and between the San Francisco and south bay peninsula and the east bay region, as well as between two major international airports (OAK and SFO). Disruption of this segment of I-80 would have significant impacts on worker access to local and regional jobs.

ASSET 5: SR-92

VULNERABILITIES

Governance Vulnerabilities (GOV)

GOV5: Work along the SR-92 corridor requires coordination with a number of regulatory agencies including BCDC, CADFW, RWQCB, and USACE because of its location between tidal marshes and managed ponds. The amount of coordination necessary can delay necessary maintenance or improvements to address future storm events and sea level rise impacts.

GOV6: Caltrans has a narrow Right-of-Way for SR-92 so any major improvements will require cooperation with adjoining property owners and managers, including the City of Hayward, EBRPD, HARD and CADFW. Adjacent property owners and managers are subject to regulatory oversight by a number of state and federal agencies due to the presence of endangered species and marsh habitat.

Physical Vulnerabilities (PHYS)

PHYS2: The western portion of SR-92 (west of Whitesell Road) is within the existing 100-year floodplain. Flood risk will increase in extent, depth and duration due to sea level rise in this area as it is already low lying.

PHYS3: There are two 2,000 fuel storage tanks kept on site at the toll plaza. While these tanks are permanent and not mobile they could be vulnerable to damage or failure if not constructed to withstand wind, wave or tidal energy. Damage to these tanks would result in the diesel and gasoline stored in them to enter the Bay.

PHYS4: The toll plaza for SR-92 relies on electrical components that are not protected from flooding and would be damaged by salt water exposure.

PHYS5: Saltwater intrusion and a rising groundwater table may cause corrosion problems for metal pipes, reinforcing in concrete structures, and pump equipment that are necessary to maintain operations at the toll plaza and this segment of SR-92. A high groundwater table can damage at-grade pavement structural sections if they are constantly saturated, ruin landscaping, and cause major dewatering problems for future construction.

Functional Vulnerabilities (FUNC)

FUNC1: There are no adequate local alternatives to cross the Bay as the Dumbarton Bridge and approaches has a similar exposure and vulnerability to sea level rise and storm events as SR-92.

FUNC2: SR-92 carries AC Transit Route M which connects the MTC Communities of Concern of Hayward and Union City to the goods, services and jobs on the peninsula. There are no adequate alternative transit options (e.g., rail or ferry).

CONSEQUENCES

Equity
SR-92 carries transit riders to and from MTC Communities of Concern in Hayward and Union City. If the road is closed temporarily, these riders may not be able to access jobs or other services as there are no alternative transit option along the Hayward-San Mateo Bridge (no ferry service, no BART).

Environment
Fuel tanks at the SR-92 toll plaza could pose a risk to local water quality and habitat if they were to topple or failed during a storm event (these tanks are elevated and store fuel for Caltrans maintenance vehicles).

Economy
SR-92 carries 91,000 drivers and 6,000 trucks each day. Even a temporary closure of the road would have significant impacts on regional commuter movement since there is no local alternative to the Hayward-San Mateo Bridge.

AGENCY SPECIFIC VULNERABILITIES AND CONSEQUENCIES - BART

ASSET 1: MULTIPLE

VULNERABILITIES

Informational Vulnerabilities (INFO)

INFO1: Asset engineering details is available as PDFs from an electronic repository. Specialized knowledge of the asset’s history is however required to reconstruct the condition of the asset, by combining information from AS BUILT drawings from relevant capital improvement projects with original design documents. Some drawings are available in CAD format upon request.

INFO2: Information on asset condition is institutionalized knowledge held by maintenance personnel. There are some datasets such as OCC logs, maintenance/inspection reports that have an indication of asset condition but these do not always provide a clear understanding of existing condition.

INFO3: There is a general lack of knowledge or understanding in the region about how sea level rise will affect the groundwater table and how changes in groundwater levels or salinity may affect the integrity of saturated assets (example: structural foundations).

Governance Vulnerabilities (GOV)

GOV1: Use changes, upgrades, or retrofits that extent beyond the BART Right-of-Way will require coordination with adjacent property owners and asset managers. In highly developed portions of the BART system, or where long stretches of BART assets are vulnerable, the number of adjacent property owners and asset managers could be large, and coordination efforts could be challenging.

GOV2: Without a regulatory mechanisms or requirement, planning to improve BART system climate resilient will be self-driven. Resources (including financing) to consider and address climate change will be prioritized if BART's upper management recognizes and prioritizes the criticality of adaption.

GOV3: Responding to identified climate vulnerabilities (e.g., adaptation actions) must consider first and foremost the safety and operability of BART services. BART adheres to safety rules that are subject to state and federal regulations, including OSHA, CPUC and FTA oversight.

ASSET 2: BART COLISEUM (COMPONENTS: TRACTION POWER SUBSTATION, TRAIN CONTROL ROOM, A30 PEDESTRIAN TUNNEL)

VULNERABILITIES

Governance Vulnerabilities (GOV)

GOV1: BART Facility Standards (BFS) requires that facility design accounts for the 100-year storm event and 500-year flood stage for critical assets, but does not require the consideration of changes to extreme tides due to sea level rise.

Physical Vulnerabilities (PHYS)

PHYS1: The traction power substation is at-grade with some protective curbing. It was not constructed to be exposed to water or salinity and therefore is not likely to be flood resistant.

PHYS2: Train control equipment is at-grade and housed, but was not constructed to be exposed to water or salinity and therefore is not likely to be flood resistant.

PHYS3: The Automatic fare collection (AFC) stations are at grade and were not constructed to be exposed to water or salinity and therefore are not likely to be flood resistant.

PHYS4: The A30 tunnel (pedestrian bridge) is below-grade; there is a sump pump that helps keep the tunnel dry, however this pump system was not designed for major overland flooding events and may be taxed by consistently very high groundwater.

PHYS5: The station's access at-grade will be impacted by flooding of adjacent local streets and roads.

Functional Vulnerabilities (FUNC)

FUNC1: BART has ongoing communication with Coliseum event coordinators to plan for increased level of service during scheduled events but not to coordinate on disruption of service.

FUNC2: The connection to AC Transit which stops at the station could be disrupted if local streets and roads are flooded.

FUNC3: BART has an existing agreement with AC Transit to provide a bus bridge if there is a service disruption, however AC Transit does not have the ability to replace the full level of service BART provides to/from this station. AC Transit is a sufficient alternative for short term disruptions (off load people already on trains) but not for long term disruptions.

FUNC4: This station provides the sole connection via a transfer platform to the Oakland Airport Connector. Disruption of this station would impact the OAC which scheduled to go online end of 2014 (replacing existing AirBARTbus bridge).

FUNC5: The A30 tunnel (pedestrian bridge) connects directly to the Coliseum station parking lot and provides the most direct access to the station. The alternate pedestrian route to the station is not as direct, and may not be safe.

CONSEQUENCES

Equity
Surrounding neighborhoods of Fruitvale and East Oakland are MTC community of concern and rely on this BART station for transit service. Disruption of this station could affect local riders, but could also affect BART's ability to serve transit dependent populations throughout the rest of the system.

Economy
Disruption of service will cause significant economic losses to BART (revenue loss) and to the greater region as BART is a major transit provider that allows people to access jobs, goods and services.

Due to the high cost of BART assets, replacement or repair of damaged assets could be costly for taxpayers, and time to restore the asset could easily be months or years depending on the damage.

Disruption of this station will affect connecting commuters between the A (to Fremont), L (to Dublin/Pleasanton) line, and rest of the system.

Environment
Hazardous materials (oil transformer at the substation is 1200 gallons; biohazard waste pail) from station could be released/exposed during flooding. Alternative modes of transportation, such as personal car, may be less environmentally friendly.

ASSET 3: BART OAKLAND AIRPORT CONNECTOR (OAC) (COMPONENTS: WHEELHOUSE (DOOLITTLE MAINTENANCE FACILITY), STATIONS AT EITHER END, TUNNEL)

VULNERABILITIES

Governance Vulnerabilities (GOV)

GOV1: BART owns the OAC, but Dopple-Mayer will manage operations and maintenance, including sump pumps to provide drainage during storm events. The Dopple-Mayer Management Plan is in progress, but only a 20-year contract and not incentivized to consider more frequent storm events due to sea level rise. Adaptation may require coordination with Dopple-Mayer which may be out of scope with their contract.

GOV2: OAC design is highly unlikely to have considered sea level rise impacts as high level State guidance has not yet translated to project design. The lack of new design standards can potentially jeopardize the useful project lifetime.

Physical Vulnerabilities (PHYS)

PHYS1: The OAC has a portion that is in a tunnel below grade and vulnerable to increased flooding due to storm events and sea level rise. Sump pump were most likely designed to manage current groundwater intrusion or rainfall runoff and will not have the capacity to handle flows during a significant flooding events.

PHYS2: The OAC has a diesel emergency generator but it is located at grade in the wheel house.

PHYS3: The wheelhouse substation is at grade and was not designed to be water or salt tolerant.

PHYS4: The switchgear cabinets at the airport station are at grade and are not designed to be water or salt tolerant.

Functional Vulnerabilities (FUNC)

FUNC1: The OAC extends from the BART Coliseum Station to the Oakland International Airport and relies on existing structural shoreline protection, owned and managed by others. The system of structural shoreline protection was not designed for future storm event water levels that will occur as sea level.

FUNC2: Flooding of the track that passes through the tunnel would disrupt services of the OAC.

FUNC3: There are no good alternatives to access the airport if the OAC flooded because the local streets and roads that lead to the airport will also be flooded and impassible in particular near the OAC tunnel location.

FUNC4: The sole function of the OAC is to provide transit access to the Oakland International Airport. If operations of the airport are disrupted the OAC will not have a purpose.

FUNC5: Access to the OAC relies on the ongoing operation of the Coliseum BART station. Disruption to this station or the adjacent local streets and roads would inhibit passenger access to the OAC.

CONSEQUENCES

Equity
Disruption may inhibit BART's ability to serve transit dependent populations making trips to and from the airport.

Economy
Loss of the OAC will affect BART through loss of revenue and the cost to repair damage to asset.

Loss of the OAC will have consequences on the business at the airport and possibly on passenger use of the airport.

Environment
Hazardous materials (diesel in emergency generator) could be released / exposed during flooding.

Alternative modes of transportation, such as personal car, may be less environmentally friendly.

ASSET 4: BART WEST OAKLAND PORTAL AREA

VULNERABILITIES

Informational Vulnerabilities (INFO)

INFO1: All information relating to the Transbay Tube (TBT) is Security Sensitive Information (SSI), which limits the access to those outside of BART that maybe necessary for understanding vulnerability and risk.

Governance Vulnerabilities (GOV)

GOV1: BART Facility Standards (BFS) requires that facility design accounts for the 100-year storm event and 500-year flood stage for critical assets, but does not require the consideration of changes to extreme tides due to sea level rise.

Physical Vulnerabilities (PHYS)

PHYS1: The transition structure is below grade and below sea level. This component relies on electrical and mechanical components that are neither water nor salt tolerant.

PHYS2: Sump pumps used to manage groundwater and rainfall runoff in the entry to the transition structure outlet to locations that may become submerged as sea level rises, decreasing the efficiency of the sump pumps and possibly limiting their functionality.

Functional Vulnerabilities (FUNC)

FUNC1: The TBT is BART's primary corridor linking the East Bay and the San Francisco peninsula. If the TBT is flooded or damaged there will be significant BART service disruptions and delays, and the alternative routes (roadways and transit) have insufficient capacity to handle a full commute period without significant lengthening of travel times.

FUNC2: Because the BART system assets are interconnected disruption or damage to the TBT will have system wide impacts.

CONSEQUENCES

Equity
The TBT serves transit riders access throughout the BART system. Disruption would inhibit BART's ability to serve transit dependent populations in particular those traveling from the East Bay to/from the San Francisco peninsula.

Economy
Disruption of service will cause significant economic losses to BART (revenue loss) and to the greater region as BART is a major transit provider that allows people to access jobs, goods and services.

Due to the high cost of BART assets, replacement or repair of damaged assets could be costly for taxpayers, and time to restore the asset could easily be months or years depending on the damage.

Environment
Hazardous materials (transformer oil) at the substation could be released/exposed during flooding. Alternative modes of transportation, such as personal car, may be less environmentally friendly.

TASK 4: STRATEGY COMPENDIUM

Introduction to document

This document consists of 8 sections - with strategies organized by core asset by focus area, by regional strategy and by agency specific strategy as follows:

- Bay Bridge - Core
- Coliseum - Core
- Hayward - Core
- Bay Bridge Regional
- Coliseum Regional
- Hayward Regional
- Caltrans - agency specific
- BART - agency specific

The following information is provided for each strategy:

VULNERABILITY	As provided by TT - physical, functional, informational, governance vulnerabilities
VULNERABILITY REFINEMENT	As refined by CT
STRATEGY	Description of strategy
POINT OF INTERVENTION	Uses the categories developed by the ART project to identify type of mechanism, in particular trying to identify existing processes or mechanisms that the strategy could fit into: - Capital planning - Codes and standards - Emergency and Hazards Planning - Project planning and design - Long-range planning - Land Use Planning - Operations - New initiatives - Agency Specific (new category)
PARTNERS	Who would be involved in implementing the strategy
TIMING	Related to exposure horizon, asset remaining life, synergy with planned projects (core or adjacent assets), implementation of adjacent or regional strategies

CORE ASSET SPECIFIC STRATEGIES
FOCUS AREA: BAY BRIDGE

ASSET	VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
I80, SFOBB toll plaza and bike path (as a collection of assets)	**I80 GOV5.** Inter-agency coordination is required for the operations and maintenance of this segment of I-80, the San Francisco-Oakland Bay Bridge (SFOBB) toll plaza, and the bike path. For example, Caltrans maintains the facilities within their Right-of-Way while the local jurisdictions are responsible for adjacent local streets. There are Maintenance Agreements with the cities of Oakland and Emeryville for the maintenance of local streets that connect to the interstate, as well as for the bike path leading to SFOBB, and a Co-op Agreement between Caltrans and BATA outlining toll plaza operations responsibilities. Changes to this segment of I-80, the toll plaza, and the bike paths will require inter-agency coordination, decision making, and potentially funding.	No additional refinement provided.	**Inter-agency coordination working group:** Planning and implementation of climate change adaptation and risk mitigation strategies in the area will require coordination between multiple agencies. Caltrans should develop a working group that would work collaboratively to address climate change-related vulnerabilities to infrastructure in the area and necessary changes to operations, decision making, and funding. The working group should include BATA, Caltrans, the City of Oakland, and the city of Emeryville.	New Initiative	BATA; Caltrans; City of Oakland; City of Emeryville	Short-term O&M opportunities; Medium-term inundation at 24".
Drainage area around I-80 segment between 40th St and Powell St	**80/580 PHYS6:** There are five separate tributary drainage areas along I-80/I-580 between the Toll Plaza and Powell Street with storm drain systems to drain water from the freeway. The capacity of this system to continue functioning as the Bay rises is unknown.	Drainage systems are designed to work with a given set of hydraulic conditions, particularly expected flow rate at the discharge point(s). If discharge is hindered such as by a rise in elevation of the bay, such that the outlets are now below the tide elevation, the drainage system could back up based on a "dam" effect as well as the additional head pressure this may create. Caltrans has the State authority to protect the public from flooding (insufficient drainage) on their facilities. However, they must coordinate with local agencies and other regulatory agencies in regards to points of discharge and quality of water from discharge. The main concern is that Caltrans additional drainage and discharge concerns are only part of the issue with the regional drainage system to which they will discharge to.	Carry out a drainage study to identify current and future capacity issues in partnership with City of Oakland and Alameda County. Depending on the outcome of that study the following drainage system modifications may be appropriate. **Drainage System Modifications:** Alternatives may include: 1. Realign drainage pipes to the minimum slope required to accommodate the design flow and raise the discharge points. 2. Reroute drainage pipes to a shorter route to a discharge point, allowing that new discharge point to be higher in elevation. 3. Add parallel drainage system as backup for the reduced flow rate in the existing system. 4. Install pumps. Monitoring conditions in the meantime will be important to see how drainage functions particularly during high tide events.	New initiative - combine modifications with recommended and scheduled Caltrans maintenance.	Caltrans Agencies with oversight of drainage flows into the Bay.	Short-term O&M opportunities; Long-term Inundation at 48"

ASSET	VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
Temescal Creek Bridge on I-80 segment between 40th St and Powell St	The capacity of the Temescal Creek Bridge to contain future extreme water levels is unknown and further studies are needed to understand how this bridge may or may not be of adequate capacity as sea level and groundwater rises.	Need to estimate the asset's pressure flow scour and if necessary evaluate structural integrity to determine if it is vulnerable to scour.	**Scour Criticality Assessment:** To better understand the capacity of bridges to contain future extreme water levels the following data would need to be collected and analyzed. 1. The datum the bridge ABPs are on and relationship to inundation mapping datum. 2. Riverine hydraulics and sea level estimates. With the velocity and water surface elevation from the riverine hydraulics along with the SLR estimates the potential pier, contraction and pressure flow scour could be estimated. Scour depths then could be compared to the foundation depths to determine if there is sufficient embedment and if the bridge is scour critical or not. If the pressure flow scour “makes” the bridge scour critical, soffit elevation could be compared to sea level rise elevations which would make the bridge scour critical. Estimates of the year the bridge would go under pressure flow could be calculated too.	New initiative	Caltrans	Review at next maintenance cycle; Long-term; inundation at 48"
Drainage area around I-880 segment between 7th St and 40th St	**I880 (7th to Toll Plaza) PHYS4.** There are five separate tributary drainage areas along I-880 between 7th Street and the Toll Plaza with storm drain systems to drain water from the freeway. The capacity of these systems to continue functioning as the Bay rises is unknown.	Drainage systems are designed to work with a given set of hydraulic conditions, particularly expected flow rate at the discharge point(s). If discharge is hindered such as by a rise in elevation of the bay, such that the outlets are now below the tide elevation, the drainage system could back up based on a "dam" effect as well as the additional head pressure this may create. Caltrans has the State authority to protect the public from flooding (insufficient drainage) on their facilities. However, they must coordinate with local agencies and other regulatory agencies in regards to points of discharge and quality of water from discharge. The main concern is that Caltrans additional drainage and discharge concerns are only part of the issue with the regional drainage system to which they will discharge to.	Carry out a drainage study to identify current and future capacity issues in partnership with City of Oakland and Alameda County. Depending on the outcome of that study the following drainage system modifications may be appropriate. **Drainage System Modifications:** Alternatives may include: 1. Realign drainage pipes to the minimum slope required to accommodate the design flow and raise the discharge points. 2. Reroute drainage pipes to a shorter route to a discharge point, allowing that new discharge point to be higher in elevation. 3. Add parallel drainage system as backup for the reduced flow rate in the existing system. 4. Install pumps. Monitoring conditions in the meantime will be important to see how drainage functions particularly during high tide events.	New initiative - combine with recommended and scheduled Caltrans maintenance.	Caltrans Agencies with oversight of drainage flows into the Bay.	Review at next maintenance cycle; Long-term Inundation at 48"
I-880 segment between 7th St and 40th St (supported aerial sections)	**I880 (7th to Toll Plaza) PHYS2:** Saltwater intrusion and a rising groundwater table may cause corrosion of the reinforcing in concrete structures that support the elevated portion of this roadway (this vulnerability needs to be double checked to determine how the footings were constructed).	Caltrans criteria for protection of reinforcing steel in concrete bridge structures has been revised since this bridge was designed. Stricter control of concrete mix designs, including additives, and greater concrete cover for both elements in salt water and adjacent to salt water.	**Concrete Sealant:** Particularly for surfaces not previously considered to be in a splash zone, apply a sealant to all surfaces that do not currently meet Caltrans current corrosion protection guidelines.	New initiative - combine with recommended and scheduled Caltrans maintenance.	Caltrans	Review at next maintenance cycle; Short-term Inundation at 12"

ASSET	VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
I-880 7th Street to the Toll Plaza	**I880 FUNC1:** There is limited redundancy for car or bus (AC Transit) commuters that rely on this segment of I-880 to access the Bay Bridge or I-80 West. Alternative routes such as I-980 to I-580 or West Grand to the toll plaza have limited additional capacity and would not be able to provide the same level of service necessary if this segment of I-880 was disrupted.	This functional vulnerability primarily gives an indication of the high consequence if the asset is inundated. Commuters accessing the Bay Bridge would access via the flyover roadway to the toll plaza. Bridge and through traffic would face disruption at lower elevations south of the flyover and at Toll Plaza. Through traffic would access other N/S interstates to avoid inundated areas. Bridge traffic would use Richmond/Golden Gate or SR 92 bridges to access the peninsula. Passenger travel can also be accommodated by additional transit service. The area is well-served by multiple transit routes and ferries that provide some level of redundancy; these agencies have mutual aid agreements and participate in emergency planning.	Note: This stretch of road would mostly be protected by focus area level strategies north of the Bay Bridge for a permanent inundation scenario. Update and Maintain RTEMP (event response): For a potential temporary inundation, an emergency plan would be implemented through the Regional Transportation Emergency Management Plan (RTEMP). Strategies would likely need to take into account of issues such as mode diversion, time of day, and local air quality to minimize local impacts. Functional strategies (e.g. alternate routes, suspended service, mode alternatives) would need to be developed at the time of the event to reflect local conditions, operating context and available resources. Enhance ITS infrastructure Information Transportation Systems present a part-physical, part-operational strategy that could allow for increased capacity on alternate roadways (or transit and ferry routes) by giving travelers up-to-date information, coordinating access to auxiliary lanes/shoulders, and planning/ communicating time of day restrictions/ incentives, or other measures. ITS infrastructure can also provide the data needed to prioritize actions. Roadway capacity Physical changes to alternate routes would occur through the agency capital plans and regional transportation plans. Physical strategies to adapt the freeway, or increase capacity on alternate routes to create redundancy, could be incorporated into state, regional and county long range transportation plans as need arises and funding permits.	Emergency and Hazard Planning New Initiatives	RTEMP members, City of Oakland, Caltrans, BART, MTC	Long term Inundation at 48"
	I880 FUNC2: There are very limited alternatives to re-route goods movement if this section of I-880 was disrupted, in particular because this segment provides the main point of access for truck traffic to/from the Port of Oakland Seaport. Re-routing truck traffic can be challenging due to road use restrictions, e.g. I-580, I-980 and local streets and roads have truck restrictions.	This functional vulnerability primarily gives an indication of the high consequence if the asset is inundated. Goods movement to/from the Port is only one part of what is largely domestic (local) goods movement need. Port access could be accommodated by (limited) northern and southern access routes. However, if at-grade sections of I-880 are flooded, access routes to the Port (Maritime Street) will also be flooded, blocking access.	Note: This stretch of road would mostly be protected by focus area level strategies north of the Bay Bridge for a permanent inundation scenario. **Update and Maintain RTEMP (event response):** For a potential temporary inundation, an emergency plan would be implemented through the Regional Transportation Emergency Management Plan (RTEMP). Strategies would likely need to take into account of issues such as mode diversion, time of day, and local air quality to minimize local impacts. Functional strategies (e.g. alternate routes, suspended service, mode alternatives) would need to be developed at the time of the event to reflect local conditions, operating context and available resources. See ITS and capacity strategy suggestions, above.	Emergency and Hazard Planning	RTEMP members, Port of Oakland, City of Oakland	Long term Inundation at 48"
I-80/I-580 segment between 40th St and Powell St (supported aerial sections)	**80/580 PHYS2:** Saltwater intrusion and a rising groundwater table may cause corrosion of the reinforcing in concrete structures that support the elevated portion of this roadway.	Caltrans criteria for protection of reinforcing steel in concrete bridge structures has been revised since this bridge was designed. Stricter control of concrete mix designs, including additives, and greater concrete cover for both elements in salt water and adjacent to salt water.	**Concrete Sealant:** Particularly for surfaces not previously considered to be in a splash zone, apply a sealant to all surfaces that do not currently meet Caltrans current corrosion protection guidelines.	New Initiative - combine with recommended and scheduled Caltrans maintenance.	Caltrans	Medium term to incorporating into O&M cycle; Long-term Inundation at 72"

ASSET	VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
I-80/I-580 segment between 40th St and Powell St (supported aerial sections)	**GOV5:** Agency coordination is required to maintain the connections between the interstate and local streets and roads. For example, the City of Oakland maintains the main connectors to I-880 from 7th Street and Grand Avenue. Caltrans does maintain some local roads (overcrossings) through maintenance agreements with the City of Oakland.	No additional refinement provided.	**Inter-agency coordination working group:** Planning and implementation of climate change adaptation and risk mitigation strategies in the area will require coordination between multiple agencies. Caltrans should develop a working group that would work collaboratively to address climate change-related vulnerabilities to infrastructure in the area and necessary changes to operations, decision making, and funding. This working group can build on existing collaborations and partnerships developed through Adapting to Rising Tides. The working group should include BATA, Caltrans, the City of Oakland, and the city of Emeryville. This strategy could also be included in updated versions of the Maintenance and Co-op Agreements between Caltrans and the local agencies. From the starting point of workshops and once a series of solutions/goals are agreed upon, the longer lasting elements of the solution – lead agency (likely Caltrans), right-of-way, environmental mitigation, design, funding, etc. can be worked out.	New Initiative	Caltrans; City of Oakland, City of Emeryville	Medium term to start agency coordination; Long-term Inundation at 72"
I-80/I-580 segment between 40th St and Powell St	**80/580 PHYS3:** Saltwater intrusion and a rising groundwater table may also cause corrosion problems for metal pipes, reinforcing in concrete structures, and pump equipment that are necessary to maintain operations at this segment of I-80/I-580. A high groundwater table can damage at-grade pavement structural sections if they are constantly saturated, ruin landscaping, and cause major dewatering problems for future construction.	Caltrans and other code criteria for protection of reinforcing steel in concrete bridge structures, other concrete structures, as well as pipes and other metal assets have been revised over the years. Stricter control of concrete mix designs, including additives, and greater concrete cover for both elements in salt water and adjacent to salt water, advanced coatings, and cathodic protection. Note that further east as the roadway extends away from the bay at the interchange with I-580 and I-880, a portion of the roadway elevation drops into a "depressed area" to an elevation of about 8 feet. This is still above the elevation of concern, but could be subject to flooding in a combined future se level rise + storm flow event where the current drainage system is overwhelmed. Given that this portion of the roadway is depressed in order to provide vertical clearance below the interchange bridges, raising the roadway is not a likely option. Providing additional barriers to prevent outside flow from entering the area and adequate drainage, including pumping if necessary is a proposed strategy.	**Raised Elevation:** Use embankment fill to raise roadway elevation to eliminate exposure. Consider retaining structures at toe of fill to minimize impact to adjacent service road and bay.	New initiative	Caltrans	Long-term Inundation at 72"
			Concrete Sealants: For concrete or metal structures, consider sealant type coatings.	New initiative - combine with recommended and scheduled Caltrans maintenance.	Caltrans	Medium term to incorporate into O&M cycle; Long-term Inundation at 72"
			Cathodic protection: For metal elements, consider cathodic protection.	New Initiative - combine with recommended and scheduled Caltrans maintenance.	Caltrans	Medium term to incorporate into O&M cycle; Long-term Inundation at 72"
			Reinforced Concrete Barrier: Construct standard Caltrans reinforced concrete barrier on either side. If risk and frequency of inundation warrants, include a composite reinforced concrete roadway, at existing grade, to form a water tight "boat" section.	New initiative	Caltrans	Long-term Inundation at 72"
	I80/I580 FUNC2: There are no local or convenient alternatives for cars, trucks or busses to cross the Bay if the SFOBB toll plaza is damaged or inoperable as the next closest crossing is 22 miles south.	This functional vulnerability gives an indication of the high consequence if the asset is flooded. Passenger travel crossing the bay could be served by ferries.	RTEMP provides for ferry and TDM alternatives implemented and coordinated in event of emergency event.	Emergency and Hazard Planning	RTEMP members: MTC, Caltrans, CHP, WETA, BART, AC Transit, ACE	RTEMP integration can be short term. Medium-term Inundation at 24"

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1-80 / I-580 Powell St. to Toll Plaza	**I80/I580 FUNC3**: This segment of I-80/I-580 carries traffic towards San Francisco and points north and south, as well as AC Transit Transbay Buses. There are alternative transit providers serving this corridor parallel to I-80/I-580 (AC Transit local buses, Capital Corridor, and BART) that could provide some redundancy for commuters, however, it is unlikely these transit providers could provide commuters an adequate alternative, both in terms of capacity and desired route, for more than a short duration disruption.	- This functional vulnerability gives an indication of the high consequence if the asset is flooded. - Alternate routes include I-80 (10 lane Interstate), San Pablo Avenue (5 Lane arterial); possibly Richmond Bridge to Marin County. - Alternate modes include BART Pittsburg and Richmond lines; AC Transit (Express on San Pablo, local routes; Transit providers include AC Transit, BART, WETA and private bus shuttles.	Note: This stretch of road would mostly be protected by focus area level strategies north of the Bay Bridge for a permanent inundation scenario. Update and Maintain RTEMP (event response): For a potential temporary inundation, an emergency plan would be implemented through the Regional Transportation Emergency Management Plan (RTEMP). Strategies would likely need to take into account of issues such as mode diversion, time of day, and local air quality to minimize local impacts. Functional strategies (e.g. alternate routes, suspended service, mode alternatives) would need to be developed at the time of the event to reflect local conditions, operating context and available resources. Enhance ITS infrastructure Information Transportation Systems present a part-physical, part-operational strategy that could allow for increased capacity on alternate roadways (or transit and ferry routes) by giving travelers up-to-date information, coordinating access to auxiliary lanes/shoulders, and planning/ communicating time of day restrictions/ incentives, or other measures. ITS infrastructure can also provide the data needed to prioritize actions. Roadway capacity Physical changes to alternate routes would occur through the agency capital plans and regional transportation plans. Physical strategies to adapt the freeway, or increase capacity on alternate routes to create redundancy, could be incorporated into state, regional and county long range transportation plans as need arises and funding permits.	Emergency and Hazard Planning	RTEMP members: MTC, Caltrans, CHP, WETA, BART, AC Transit, ACE	RTEMP integration can be short term. Medium-term Inundation at 24"
	I80/I580 FUNC4: There are limited alternatives for goods movement that rely on this section of I-80 and I-580, especially for goods bound for, or leaving, San Francisco and the peninsula and the east bay. **I80/I580 FUNC5:** There are very limited alternatives to re-route goods movement if the toll plaza or this section of I-80/I-580 was disrupted, especially for goods movement between the San Francisco peninsula and the East Bay and for goods bound to/from the Port of Oakland Seaport. Re-routing truck traffic can be challenging due to road use restrictions, e.g. I-580, I-980 and local streets and roads have truck restrictions.	-This functional vulnerability gives an indication of the high consequence if the asset is flooded. - The available bridge crossings between Alameda and SF Counties include the I-80, SR-92,and I-580 to US -101 south. - Alternative goods movement modes such as rail or truck float programs are not available. - The Marine Highway program operates freight (container) barges between Oakland and Stockton Ports, and infrastructure (cranes) are not available in SF or peninsula.	See above regarding RTEMP. **Freight barge (physical)** Explore strategies related to freight barge systems between Port of Oakland and Peninsula. Port of Oakland has crane infrastructure needed for Marine Highway; infrastructure would be needed on west side to complete system. Alternative is roll-on barge system which does not require cranes. Explore strategies developed for OAK-SFO barge/ ferry system. **BART freight hybrid** Explore strategies related to adaptation of BART infrastructure for limited goods movement (added or adapted train car) assuming tube is operational when I-80 is inundated.	Emergency and Hazard Planning	RTEMP members: MTC, Caltrans, CHP, WETA, BART, AC Transit, ACE OAK and SFO Port of Oakland Port of San Francisco	RTEMP integration can be short term. Medium-term Inundation at 24" Other strategies to be considered if protection strategies for focus area are not implemented.

ASSET	VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
I-880 segment between 7th St and 40th St	**880 (7th to Toll Plaza) PHYS3:** A rising groundwater table could damage the at-grade pavement structural section of this section of I-880 near 7th street, in particular if the roadbed is constantly saturated. Groundwater can also damage the landscaping and cause major dewatering problems for future construction.	Roadway sections are typically designed to be well drained, which is based on the water table, local weather (rain intensity, duration). If constant inundation / saturation of the roadway is expected, the roadway section would be specifically designed for that. Design also accounts for expected traffic volume and type of vehicles. For roadways with less traffic and little large truck volume, the existing roadway section, even if inundated, may still be OK. For heavy truck traffic, it will likely not be adequate.	**Raised Elevation:** Use embankment fill to raise roadway elevation to eliminate exposure. Consider retaining structures at toe of fill to minimize impact to adjacent service road and bay.	New initiative	Caltrans	Long-term; Inundation at 72"
			Road Material Replacement: Replace road section with higher quality base and surface material, that is well drained and compaction/resistance to high wheel loads, is not as effected by saturation	New initiative - combine with recommended and scheduled Caltrans maintenance.	Caltrans	Long-term; Inundation at 72"
			Protective Wall: Construct standard Caltrans reinforced concrete barrier on either side. If risk and frequency of inundation warrants, include a composite reinforced concrete roadway, at existing grade, to form a water tight "boat" section.	New initiative	Caltrans	Long-term; Inundation at 72"
I-80 Toll Plaza	**80/580 PHYS5:** Infrastructure serving this segment of I-80/I-580 are potentially susceptible to salt water intrusion/corrosion.	Roadway sections are typically designed to be well drained, which is based on the water table, local weather (rain intensity, duration). If constant inundation / saturation of the roadway is expected, the roadway section would be specifically designed for that. Design also accounts for expected traffic volume and type of vehicles. For roadways with less traffic and little large truck volume, the existing roadway section, even if inundated, may still be OK. For heavy truck traffic, it will likely not be adequate. The toll plaza is at about the same elevation as the end of the bridge. The roadway through the length of the toll plaza slopes down only a few feet. Therefore, the elevation is about 14 to 12 feet above the current bay. This is well above any future sea level + storm water rise scenario. Toll plazas are very expensive infrastructure and moving it is not currently a feasible option especially at the Bay Bridge. This is a relatively new very expansive facility that includes maintenance facilities, offices, CHP and even towing services. It is unlikely that relocating is not an option. The proposed strategies of protecting the supporting embankment against higher wave action associated with a rise in sea level is likely to be the most reasonable.	**Raised Elevation:** Use embankment fill to raise roadway elevation to eliminate exposure. Consider retaining structures at toe of fill to minimize impact to adjacent service road and bay.	New initiative	Caltrans	Dependent on focus area strategy development; Long-term Inundation at 48"
			Road Material Replacement: Replace road section with higher quality base and surface material, that is well drained and compaction/resistance to high wheel loads, is not as effected by saturation.	New initiative - combine with recommended and scheduled Caltrans maintenance.	Caltrans	Medium term to incorporate into O&M cycle; Long-term Inundation at 48"
			Protective wall: Construct standard Caltrans reinforced concrete barrier on either side. If risk and frequency of inundation warrants, include a composite reinforced concrete roadway, at existing grade, to form a water tight "boat" section.	New initiative	Caltrans	Dependent on focus area strategy development; Long-term Inundation at 48"

ASSET	VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
Tunnel under toll-plaza	**80/580 PHYS5:** Infrastructure serving the toll plaza are potentially susceptible to salt water intrusion/corrosion, for example the pump house and tunnel at the toll plaza.	The primary objective is to keep water out of the pump house and tunnel, the structures should be evaluated for additional salt water contact at the exterior/buried surfaces.	**Protective Walls:** This personnel access tunnel to the toll booths contain entrances to each booth via a stair well that has concrete walls extending above the roadway surface on three sides, with the fourth side being the access point. Raise walls to eliminate risk and install a water tight gate on the access side.	New initiative	Caltrans	Dependent on focus area strategy development; Long-term Inundation at 48"
			Surface Treatment: Also, evaluate as-built design regarding exterior surface treatment and concrete cover over rebar for susceptibility to higher levels of salt exposure.	New initiative	Caltrans	Dependent on focus area strategy development; Long-term Inundation at 48"
Power-lines in tunnel under toll plaza	**80/580 PHYS5:** Infrastructure serving the toll plaza are potentially susceptible to salt water intrusion/corrosion, for example the pump house and tunnel at the toll plaza.	Although the primary objective is to keep water out of the toll plaza access tunnel, critical life safety issues, such as maintaining lighting and communications within the tunnel even if flooded, should be addressed.	**Waterproof junctions:** Replace all power and communication lines from within access tunnel using water tight conduits and fixtures. For safety lighting with exposed fixtures, replace with underwater rated fixtures and ensure they are GFCI protected.	New initiative	Caltrans	Medium term to incorporate into O&M cycle; Long-term Inundation at 48"
			Elevate Electrical Lines: Remove all power and communication lines from within access tunnel and relocate to toll structure running above toll booths. Conduits and fixtures for lighting and emergency communication (if any) shall remain. Ensure all remaining electrified lines (safety lighting and communication) are GFCI protected., and replace lighting fixtures with underwater rated fixtures.	New initiative	Caltrans	Medium term to incorporate into O&M cycle; Long-term Inundation at 48"
East Portal TransBay Tube	**BART Portal Area PHYS1:** The transition structure is below grade and below sea level. This component relies on electrical and mechanical components that are neither water or salt tolerant.	Existing drainage pumps near the portal are not sufficient to handle the inundation associated with storm surge or sea level rise. Without additional protection there is a risk of water causing an electrical shortage between the traction electrification contact rail and the running rail. The higher water levels will result in more water seeping through the retaining wall joints. This water ends up in the bottom of the trench where the tracks enter the tunnel. It may not be a significant difference but it will be higher.	**Lateral Protective Walls:** The tube portal has a U-wall protecting the asset from flood risk to the tube entrance. This gradual descent includes parallel walls extending back to where the track is above grade. The U-wall should be reviewed for sufficiency against the target inundation scenario. If found deficient, retrofit existing wall.	New initiative	BART	Redundant depending on focus area strategies: Long-term Inundation at 72"
			Elevation or waterproof in place of mechanical/electrical system: These systems could be elevated or waterproofed in place. In order to determine feasibility, component plans should be reviewed and existing conditions inspected. This approach would require additional piping and electrical conduits. In either case new equipment will be required because the water will need to be pumped to a higher elevation.	New initiative - combine with recommended and scheduled Caltrans maintenance.		Medium term - research and track performance of plug solutions; Redundant depending on focus area strategies: Long-term Inundation at 72"
			Portal Plug: Research use of temporary gates or "stop logs" and inflatable "plugs" at times of risk. Consider unique solution being considered for Manhattan tunnels that were inundated during hurricane Sandy (see www.dhs.gov/35000-gallons-prevention). A gate would be too difficult to implement because of the various components on the floor of the tunnel (tracks, contact rails, conduits, etc.). A temporary barrier such as stop logs are common for flood protection of roadway underpasses at levees. These are manually lowered in place by small cranes or forklifts.	New initiative	BART	Medium term - research and track performance of plug solutions; Redundant depending on focus area strategies: Long-term Inundation at 72"

ASSET	VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
East Portal TransBay Tube	**BART Portal Area PHYS2:** Sump pumps used to manage groundwater and rainfall runoff in the entry to the transition structure outlet to locations that may become submerged as sea level rises, decreasing the efficiency of the sump pumps and possibly limiting their functionality.	The sump pumps they are most likely located just inside the tunnel. The sump captures water entering the tunnel along the concrete slab. The water in the sump is pumped out, usually to a local City storm drain line.	**Sump Water Outlet Relocation:** First the agency should examine if the existing outlet (e.g., city storm drain system) would be inundated at future sea level rise or storm surge situations. Relocate outlet if needed. During an isolated event the agency could just pump the water outside of the portal "barrier" but this would require a bypass hooked up to the sump pump system. You could also use temporary pumps.	New initiative	BART	Synergy with BART Earthquake Safety Program upgrades; Redundant depending on focus area strategies: Long-term Inundation at 72"
	BART Portal Area PHYS3: The track portal maintenance access gate is at grade and are not protected from overland flooding.	The portal access gate forms part of the U-Wall. The access gate was formerly waterproof; currently it is not.	**Waterproofing:** Replace/retrofit door to be waterproof as originally designed.	New initiative	BART	Redundant depending on focus area strategies; Long-term Inundation at 72".
	BART Portal Area FUNC1: The TBT is BART's primary corridor linking the East Bay and the San Francisco peninsula. If the TBT is flooded or damaged there will be significant BART service disruptions and delays, and the alternative routes (roadways and transit) have insufficient capacity to handle a full commute period without significant lengthening of travel times. **BART Portal Area FUNC2:** Because the BART system assets are interconnected disruption or damage to the TBT will have system wide impacts.	This functional vulnerability gives an indication of the high consequence if the asset is flooded. Passenger travel crossing the bay could be served by ferries, automobile and bus.	RTEMP provides for ferry and TDM alternatives implemented and coordinated in event of emergency event. Explore bicycle - pedestrian access on Bay Bridge during emergencies (path exists only Oakland to Treasure Island)	Emergency and Hazard Planning	RTEMP members: MTC, Caltrans, CHP, WETA, BART, AC Transit, ACE	Redundant depending on focus area strategies; Long-term Inundation at 72".
BART assets - general for focus area	**BART FUNC3:** BART leases space to allow for commercial fiber optic cables to run through the transbay tube. It is unclear if a flooding situation would disrupt commercial network services. And if so, to what extent would that impact be?	If the service was disrupted there could be loss of revenue. Seems like any strategies would have to be developed by the lessee since they know what would be needed to protect their asset.	Initiate conversations with lessees regarding the vulnerability of their fiber optic cables to inundation by salt water to understand what level of waterproofing or retrofit may be required to main service.	New Initiative	BART, lessees	Redundant depending on focus area strategies; Long-term Inundation at 72".
BART assets - general for focus area	**BART Portal Area FUNC1:** The TBT is BART's primary corridor linking the East Bay and the San Francisco peninsula. If the TBT is flooded or damaged there will be significant BART service disruptions and delays, and the alternative routes (roadways and transit) have insufficient capacity to handle a full commute period without significant lengthening of travel times. **BART Portal Area FUNC2:** Because the BART system assets are interconnected disruption or damage to the TBT will have system wide impacts.	This functional vulnerability gives an indication of the high consequence if the asset is flooded. Passenger travel crossing the bay could be served by ferries, automobile and bus.	RTEMP provides for ferry and TDM alternatives implemented and coordinated in event of emergency event. Explore bicycle - pedestrian access on Bay Bridge during emergencies (path exists only Oakland to Treasure Island)	Emergency and Hazard Planning	RTEMP members: MTC, Caltrans, CHP, WETA, BART, AC Transit, ACE	Redundant depending on focus area strategies; Long-term Inundation at 72".

CORE ASSET SPECIFIC STRATEGIES
FOCUS AREA: COLISEUM

ASSET	VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
I-880: Tributary Drainage Area	**880 (Coliseum to 98th) PHYS5:** There are three separate tributary drainage areas along I-880 between the 66th Avenue and 98th Avenue with Caltrans operated storm drain systems to drain water from the freeway. Although most of the inlets, outfalls, discharge points, junction boxes, and storm pipes are listed as in good condition, the capacity of this system to continue functioning as the Bay rises is unknown. These systems ultimately discharge to Alameda County and City of Oakland drainage assets.	Drainage systems are designed to work with a given set of hydraulic conditions, particularly expected flow rate at the discharge point(s). If discharge is hindered such as by a rise in elevation of the bay, such that the outlets are now below the tide elevation, the drainage system could back up based on a "dam" effect as well as the additional head pressure this may create.	Carry out a drainage study to identify current and future capacity issues in partnership with City of Oakland and Alameda County. Depending on the outcome of that study the following drainage system modifications may be appropriate. **Drainage System Modifications:** Alternatives may include: 1. Realign drainage pipes to the minimum slope required to accommodate the design flow and raise the discharge points. 2. Reroute drainage pipes to a shorter route to a discharge point, allowing that new discharge point to be higher in elevation. 3. Add parallel drainage system as backup for the reduced flow rate in the existing system. 4. Install pumps. Monitoring conditions in the meantime will be important to see how drainage functions particularly during high tide events.	New initiative	Caltrans Agencies with oversight of drainage flows into the Bay.	Medium term to incorporate into O&M cycle; Long-term Inundation at 48"
I-880 from Coliseum Way to 98th Avenue	**I880 (Coliseum to 98th) FUNC1:** This segment of I-880 serves the Oakland International Airport, in particular via the Hegenberger and 98th street exits. There are no adequate alternative routes to access the airport as the only option would be local streets and roads that do not have similar capacity.	If I-880 is disrupted, OAK access and operations are also likely disrupted, reducing demand on route. Alternate routes include I-580 (8 lane Interstate), San Leandro Street (5 Lane arterial), and International Boulevard / East 14th Avenue (4-lane arterial). Each of these routes access streets (i.e. Hegenberger and 98th Street) leading to the Oakland International Airport. Alternate modes include BART Fremont line (elevated) and AC Transit (BRT on International Blvd, local routes on east-west and north-south access routes).	**Update and maintain RTEMP (event response)** Update and maintain Regional Transportation Emergency Management Plan (RTEMP) to ensure adequate user and agency information to prepare for, respond to and recover from SLR-related events. Examples include: updated 511 traveler information, suspending or controlling route access, implement strategies under transportation agency mutual aid agreements. **Improve transit capacity (long-term planning)** Ensure transit agencies and partners explore long-term transit routes related to changing shoreline, if physical mitigations do not maintain existing. Transit strategies would decrease demand on arterials and freeways and may include increased service frequency, route efficiency (i.e. transit signal priority and dedicated lanes), higher capacity technology (i.e. rail), and park-and-ride facilities.	Emergency and Hazard Planning	RTEMP members: MTC, Caltrans, CHP, WETA, BART, AC Transit, ACE	Start incorporating SLR considerations into next major update of RTEMP (last one done in 2008).
	I880 (Coliseum to 98th) FUNC2: There is limited redundancy for commuters that rely on this segment of I-880. Alternative routes include local streets and frontage roads that can not accommodate the same capacity as this section of I-880. The use of I-580 as an alternative would require a significant rerouting of traffic and there is not the capacity to provide the same level service.	Alternate routes include I-580 (8 lane Interstate), San Leandro Street (5 Lane arterial), and International Boulevard / East 14th Avenue (4-lane arterial). Each of these routes access streets (i.e. Hegenberger and 98th Street) leading to the Oakland International Airport. Alternate modes include BART Fremont line (elevated); AC Transit (BRT on International Blvd, local routes on east-west and north-south access routes); and Capitol Corridor commuter rail		Emergency and Hazard Planning	RTEMP members: MTC, Caltrans, CHP, WETA, BART, AC Transit, ACE	Start incorporating SLR considerations into next major update of RTEMP (last one done in 2008).

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I-880 from Coliseum Way to 98th Avenue	**I880 (Coliseum to 98th) FUNC3:** There are many transit operators that serve a corridor parallel to I-880 (AC Transit, Capital Corridor, and BART), however, it is unlikely these transit providers could provide commuters an adequate alternative, both in terms of capacity and desired route, for more than a short duration disruption.	Alternate modes include BART Fremont line (elevated); AC Transit (BRT on International Blvd, local routes on east-west and north-south access routes); and Capitol Corridor commuter rail		Emergency and Hazard Planning	RTEMP members: MTC, Caltrans, CHP, WETA, BART, AC Transit, ACE	Start incorporating SLR considerations into next major update of RTEMP (last one done in 2008).
	I880 (Coliseum to 98th) FUNC4: There are very limited alternatives to re-route goods movement if this section of I-880 was disrupted, in particular because this segment provides the main point of access for truck traffic to/from the Port of Oakland Seaport. Re-routing truck traffic can be challenging due to road use restrictions, e.g. I-580, I-980 and local streets and roads have truck restrictions	Goods movement to and from the Port is one part of comprehensive goods movement; the majority of goods movement needs are domestic (inter or intraregional); goods movement access to OAK is also economically critical. I-580 has heavy truck restrictions for operational purposes; no indication the roadway cannot accommodate temporary weight and capacity loads. Alternate parallel truck routes include San Leandro Road (designated truck route) and International Boulevard (no restrictions)	**Temporary use of I-580:** Allow temporary use of I-580 in event of SLR-related restriction.	Emergency and Hazard Planning	RTEMP members: MTC, Caltrans, CHP, WETA, BART, AC Transit, ACE	Start incorporating SLR considerations into next major update of RTEMP (last one done in 2008).
I-880 Damon Slough Bridge	**880 (Coliseum to 98th) PHYS6:** The Damon Slough Bridge has been noted to have water levels close to the road deck at extremely high tide indicating that it is likely already undersized. Sea level rise will exacerbate this issue as the bridge will likely be under capacity more frequently at high tide.	As the tide rises, future storm flows could experience a backup due to a flattening of the hydraulic flow line (difference in elevation between up stream flow and mouth of slough as it enters the bay near the bridge will be reduced). This will cause a backup (increased elevation) at the bridge.	**Flow Restriction Reduction:** 1.Widen creek under and downstream of bridge. May require partial channelization of creek with concrete walls or gabion type of earth retaining structure. 2. Add culverts (pipes jacked under roadway) under Hwy 880 to provide for a supplemental flow path for the creek at times of high flows.	New initiative	Caltrans Agencies with oversight of the creek and flows. Landowners adjacent to creek	(Need to review short term capital planning projects in this area) Short-term Inundation at 12"
	880 (Coliseum to 98th) PHYS3: Increases in wind, wave or tidal energy as the Bay rises could increase the scour at the abutments of the Damon Slough Bridge and erosion in the flood control channel both up and downstream of the bridge.	Typically, scour protection is based on hydrologic studies as to type and extent of protection. If this data from hydrologic studies is updated, the scour protection requirements would also change.	**Pier Scour Counter measures:** If bridge is determined to be scour critical, typical pier scour countermeasures might include: a) rock slope protection at the piers, b) partially grounted riprap, c) articulating concrete blocks Provide scour protection at embankments for abutments if required due to increased scour risk from inflow and outflow of high tide and storm events. Confirm that bridge super structure type can withstand flow and wave action. Obtain as-built plans to determine if bridge superstructure is columns and bent caps composite with super structure (resistant to lateral flow and wave forces), or on bearings (posing a risk due to lateral flow and wave forces).	New initiative - combine with recommended and scheduled Caltrans maintenance.	Caltrans Agencies with oversight of the creek and flows. Potentially landowners adjacent to creek	(Need to review short term capital planning projects in this area) Short-term

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I-880 Damon Slough Bridge	**880 (Coliseum to 98th) PHYS2:** Saltwater intrusion and a rising groundwater table may cause corrosion of the reinforcing in concrete structures that support the elevated portion of this roadway and the Damon Slough crossing.	Caltrans criteria for protection of reinforcing steel in concrete bridge structures has been revised since this bridge was designed. Stricter control of concrete mix designs, including additives, and greater concrete cover for both elements in salt water and adjacent to salt water.	**Concrete Sealant:** Particularly for surfaces not previously considered to be in a splash zone, apply a sealant to all surfaces that do not currently meet Caltrans current corrosion protection guidelines.	New initiative - combine with recommended and scheduled Caltrans maintenance.	Caltrans	Short term to incorporate into O&M cycle; Short-term Inundation at 12"
	INFO5: The capacity of the Damon Slough Bridge to contain future extreme water levels is unknown and further studies are needed to understand how these bridges may or may not be of adequate capacity as sea level and groundwater rises.	Need to estimate the asset's pressure flow scour and if necessary evaluate structural integrity to determine if it is vulnerable to scour.	**Scour Criticality Assessment:** To better understand the capacity of bridges to contain future extreme water levels the following data would need to be collected and analyzed. 1. The datum the bridge ABPs are on and relationship to inundation mapping datum. 2. Riverine hydraulics and sea level estimates. With the velocity and water surface elevation from the riverine hydraulics along with the SLR estimates the potential pier, contraction and pressure flow scour could be estimated. Scour depths then could be compared to the foundation depths to determine if there is sufficient embedment and if the bridge is scour critical or not. If the pressure flow scour "makes" the bridge scour critical, soffit elevation could be compared to sea level rise elevations which would make the bridge scour critical. Estimates of the year the bridge would go under pressure flow could be calculated too.	New initiative	Caltrans	(Need to review short term capital planning projects in this area) Short-term Inundation at 12"
I-880 Elmhurst Creek Bridge	**880 (Coliseum to 98th) PHYS3:** Increases in wind, wave or tidal energy as the Bay rises could increase the scour at the abutments of the Elmhurst Slough Bridge and erosion in the flood control channel both up and downstream of the bridge.	Typically, scour protection is based on hydrologic studies as to type and extent of protection. If this data from hydrologic studies is updated, the scour protection requirements would also change.	**Pier Scour Countermeasures:** If bridge is determined to be scour critical, typical pier scour countermeasures might include: a) rock slope protection at the piers, b) partially grounted riprap, c) articulating concrete blocks Provide scour protection at embankments for abutments if required due to increased scour risk from inflow and outflow of high tide and storm events. Confirm that bridge super structure type can withstand flow and wave action. Obtain as-built plans to determine if bridge superstructure is columns and bent caps composite with super structure (resistant to lateral flow and wave forces), or on bearings (posing a risk due to lateral flow and wave forces).	New initiative - combine with recommended and scheduled Caltrans maintenance.	Caltrans Agencies with oversight of the creek and flows. Potentially landowners adjacent to creek	Medium term for investigation in line with other relevant planned projects; Medium -term Exposure to 24" inundation

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I-880 Elmhurst Creek Bridge	**INFO5:** The capacity of the Elmhurst Creek Bridge to contain future extreme water levels is unknown and further studies are needed to understand how these bridges may or may not be of adequate capacity as sea level and groundwater rises.	Need to estimate the asset's pressure flow scour and if necessary evaluate structural integrity to determine if it is vulnerable to scour.	**Scour Criticality Assessment:** To better understand the capacity of bridges to contain future extreme water levels the following data would need to be collected and analyzed. 1. The datum the bridge ABPs are on and relationship to inundation mapping datum. 2. Riverine hydraulics and sea level estimates. With the velocity and water surface elevation from the riverine hydraulics along with the SLR estimates the potential pier, contraction and pressure flow scour could be estimated. Scour depths then could be compared to the foundation depths to determine if there is sufficient embedment and if the bridge is scour critical or not. If the pressure flow scour "makes" the bridge scour critical, soffit elevation could be compared to sea level rise elevations which would make the bridge scour critical. Estimates of the year the bridge would go under pressure flow could be calculated too.	New initiative	Caltrans	Medium term for investigation in line with other relevant planned projects; Medium -term Exposure to 24" inundation
	880 (Coliseum to 98th) PHYS2: Saltwater intrusion and a rising groundwater table may cause corrosion of the reinforcing in concrete structures that support the elevated portion of this roadway and Elmhurst Slough crossing.	Caltrans criteria for protection of reinforcing steel in concrete bridge structures has been revised since this bridge was designed. Stricter control of concrete mix designs, including additives, and greater concrete cover for both elements in salt water and adjacent to salt water.	**Concrete Sealant:** Particularly for surfaces not previously considered to be in a splash zone, apply a sealant to all surfaces that would not meet Caltrans current corrosion protection guidelines.	New initiative - combine with recommended and scheduled Caltrans maintenance.	Caltrans	Short term to incorporate into O&M cycle; Medium-term Exposure to 24" inundation
Coliseum BART Station	**BART Coliseum PHYS5:** The station's access at-grade will be impacted by flooding of adjacent local streets and roads.	No additional refinement provided.	**Drainage and Diversion** Consider combination of increased drainage capacity, pumps if needed, away from station entrance and ingress/egress paths.	New initiative - combine with recommended and scheduled Caltrans maintenance.	City of Oakland	Dependent on focus area strategy development; Long-term Inundation at 72"
	BART Coliseum FUNC1: BART has ongoing communication with Coliseum event coordinators to plan for increased level of service during scheduled events but not to coordinate on disruption of service.	BART is part of the Regional Transportation Emergency Management Plan (RTEMP) which addresses transportation for general public transportation services; BART also participates in Transportation Coordination and Response Plan to accommodate transportation for emergency response workers.	**Update and maintain RTEMP (event response)** Maintain RTEMP and Transportation Coordination and Response Plan and Mutual Aid Agreements to ensure sufficient capacity in event BART service is disrupted. Consider including CCJPA and Amtrak in the RTEMP planning, in order to identify further increased passenger capacity if Amtrak operates while BART does not.	Emergency and Hazard Planning	RTEMP members: MTC, Caltrans, CHP, WETA, BART, AC Transit, ACE	Start incorporating SLR considerations into next major update of RTEMP (last one done in 2008).

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Coliseum BART Station	**BART Coliseum FUNC2:** The connection to AC Transit which stops at the station could be disrupted if local streets and roads are flooded.	The Coliseum BART station would be closed when surface streets / sidewalks are flooded.	**Update and maintain RTEMP (event response)** Maintain RTEMP and Transportation Coordination and Response Plan to ensure alternate routes/shuttles are available to/from other BART stations.	Emergency and Hazard Planning	RTEMP members: MTC, Caltrans, CHP, WETA, BART, AC Transit, ACE	Start incorporating SLR considerations into next major update of RTEMP (last one done in 2008).
	BART Coliseum FUNC3: BART has an existing agreement with AC Transit to provide a bus bridge if there is a service disruption, however AC Transit does not have the ability to replace the full level of service BART provides to/from this station. AC Transit is a sufficient alternative for short term disruptions (off load people already on trains) but not for long term disruptions.	Flooding may impact ground-level BART infrastructure and/or communication equipment causing a BART service disruption without blocking local roads.	**Update and maintain RTEMP (event response)** Maintain RTEMP, Transportation Coordination and Response Plan, and Mutual Aid Agreements to ensure sufficient capacity over disruption period (respond, recover, mitigate). Strategies may include diversion to alternate modes, transportation demand management (e.g. working remotely), and replaced capacity. **Physical strategies (long-term planning)** Functional strategies will not address incremental SLR. Physical changes to BART infrastructure would occur through the agency capital plans and regional transportation plans.	Emergency and Hazard Planning	RTEMP members: MTC, Caltrans, CHP, WETA, BART, AC Transit, ACE	Start incorporating SLR considerations into next major update of RTEMP (last one done in 2008).
	BART Coliseum FUNC4: This station provides the sole connection via a transfer platform to the Oakland Airport Connector. Disruption of this station would impact the OAC which scheduled to go online end of 2014 (replacing existing AirBARTbus bridge).	If Coliseum is flooded, it is likely that OAK and OAC access will be flooded, unless adaptation strategies are implemented at OAK.	RTEMP updates should include OAC once implemented. OAC service could be replaced by bus service if access roads and OAK are minimally or not disrupted. OAC service could be replaced by routes to/from other BART stations as needed if only Coliseum station is disrupted.	Emergency and Hazard Planning	RTEMP members: MTC, Caltrans, CHP, WETA, BART, AC Transit, ACE	Start incorporating SLR considerations into next major update of RTEMP (last one done in 2008).

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Coliseum BART Pedestrian Tunnel	**BART Coliseum PHYS4:** The pedestrian tunnel is below-grade; there is a sump pump that helps keep the tunnel dry, however this pump system was not designed for major overland flooding events and may be taxed by consistently very high groundwater.	No additional refinement provided.	The pedestrian tunnel will be in service for the foreseeable future. However, a measure on the fall 2014 ballot will ask Alameda County voters to approve a sales tax for transportation projects. If it passes, funding will be available to purchase the underutilized UPRR Oakland Subdivision and convert the ROW to a multi-purpose trail. Other funding sources for the ROW acquisition and trail implementation have not been identified other than the sales tax measure. If a trail project becomes reality through passage of the sales tax measure, BART would likely begin to plan and design a modification to the existing station to close the underpass and allow ground-level access from the east side of the station. This would require additional funding that BART has not yet procured or programmed. The cost of purchasing the UPRR ROW may be prohibitive if solely to allow BART to close the underpass and introduce ground-level access, the incremental cost of modifying the station for ground-level access once the UPRR ROW is acquired for trail use would likely be less than (or at the very least comparable) to the cost of a pedestrian overpass as indicated below. The modification allowing ground-level access would have benefits beyond SLR adaptation (e.g., enhanced customer experience, reduced expenses for maintenance of wheelchair lifts) and this cost-effectiveness would make the project competitive for sources of funding other than those targeted for adaptation projects alone.	New Initiative	BART, UPRR	Dependent on focus area strategy development; Long-term Inundation at 72"
			Pedestrian Overpass: Construct pedestrian bridge over Snell Street and UPRR track.	New Initiative	BART	Dependent on focus area strategy development; Long-term Inundation at 72"
Coliseum BART Station Traction Power Sub-Station	**BART Coliseum PHYS1:** The traction power substation is at-grade with some protective curbing. It was not constructed to be exposed to water or salinity and therefore is not likely to be flood resistant. The existing TPSS components are currently being replaced however the new components are being installed at the essentially the same elevation as the existing ones.	The new components will be raised a few inches to allow containment of oil leaking out of the transformers.	**TPSS Berm:** A berm can be constructed around the TPSS to contain SLR and storm surge in the nearer term. The berm would need to include ramps to allow equipment to be replaced within the TPSS as necessary.	Capital planning	BART	Sub station undergoing renovation. Outcome of that will influence strategy going forward. Long term inundation at 72"
			TPSS Elevation (Relocation): The service life of the TPSS components is approximately 40 years. Once the new facility components have exhausted their service life a new facility can be constructed at an alternative location with a raised elevation. Any raised elevation strategy will need to consider the allowable tolerance from top of asset to the underside of the aerial trackway.	Capital planning	BART	

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Coliseum BART Station Control Room	**BART Coliseum PHYS2:** Train control equipment is at-grade and housed, but was not constructed to be exposed to water or salinity and therefore is not likely to be flood resistant.	The control room includes electronic equipment for train control, communications, and station security. Inundation by storm surge would lead to loss of equipment function and cripple BART services at the station.	**Control Room Elevation (Same location):** Keep the existing control room and raise the non water resistant equipment off the floor to prevent contact with storm water entering the room. Confirm that head room (below station floor) above control room equipment is adequate to raise control room floor to an elevation above flood risk.	New initiative	BART	Dependent on focus area strategy development; Long-term Inundation at 72"
			Control Room Elevation (Relocation): This strategy requires construction of a new control room nearby at a higher elevation to keep equipment clear of SLR and SS. The existing control room will stay functional during construction of the new facility. The "cut over" from the old facility to the new one would be performed during non-operational hours and may require a staged transition.	New initiative	BART	
			Ring Levee: Provide a watertight retaining wall around the control room with water resistant access gates. Similar in concept to containment structures around above ground tanks, with opposite intent - keep water out, rather than contained. Containment would be constructed as reinforced concrete walls with composite base slab if needed. Ramps will be needed to allow access to the building by forklift or other means to facilitate movement of equipment within the building.	New initiative	BART	
Coliseum Bart Station - Underground Power Lines/Pull-Boxes	**BART Coliseum PHYS3:** The Automatic fare collection (AFC) stations are at grade and was not constructed to be exposed to water or salinity and therefore is not likely to be flood resistant.	Power-lines/pull-boxes for fire-alarms, smoke-detectors, security-cameras and TVs, announcement controls, security controls, and fiber-optic lines at the Coliseum BART station are all underground, and highly vulnerable to storm-surge. In addition to physical damage from storm-surge, the power lines may also be susceptible to corrosion from salt water intrusion. Power-lines/pull-boxes serving lighting are all above ground.	**Electrical Equipment Relocation:** Electrical pullboxes and vaults can be relocated to an above-ground location however they would have to be placed at a location away from street and pedestrian traffic. Electrical cables are insulated which normally provides protection against exposure to water and various corrosive liquids. An alternative strategy would include relocation of duct banks to a location where pullboxes and vaults could be accessible for maintenance without interference from motor vehicles and pedestrians.	New initiative	PG&E, BART	Dependent on focus area strategy development; Long-term Inundation at 72"
Oakland Coliseum Amtrak Station	**Amtrak PHYS1:** The station was built as slab-on-grade of materials not intended to withstand flooding of any duration. Mechanical and electrical equipment (e.g. ticket machines, lighting, electronic notification system) that are essential to the safe operation of the station will be damaged by exposure to water and/or salinity.	It would be infeasible to raise the entire facility (including track) to an elevation above the anticipated SLR of 72". The tracks cannot be raised due to the proximity of adjacent roadway overcrossing structures.	**Berm:** A berm or wall would need to be constructed around the entire Amtrak station complex, and extended along both sides of the tracks to a point where the anticipated SLR would be below the track ballast.	Any strategy would be timed with potential new development at Amtrak station	AMTRAK; adjacent property and land owners	Dependent on focus area strategy development; Long-term Inundation at 72"

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Oakland Coliseum Amtrak Station	**Amtrak PHYS2:** The safe operation of the station relies on utilities that are below-grade. Specifically, the underground pump station managed by ACWCFCD and utilities owned by PG&E, Comcast, and AT&T that are located in the area along San Leandro Street from 75th to 66th Avenue including 73rd Avenue. Electrical and mechanical equipment are generally not water or saltwater proof, even if located below-grade, and rising groundwater or overland flooding could disrupt these elements.	The anticipated SLR facilities surrounding the Amtrak station. All underground electrical and mechanical equipment are subject to risk due to potential groundwater intrusion.	**Electrical Equipment Elevation:** All electrical and mechanical equipment would have to be raised above the anticipated 72" SLR or higher to provide protection against greater SLR levels.	New initiative / Project Planning and Design	City of Oakland, AMTRAK, UP, CCJPA.	Dependent on focus area strategy development; Long-term Inundation at 72"
	Amtrak PHYS3: The station is located in an area with high liquefaction potential if there was a seismic event. Neither the station nor the rail track will be able to withstand high levels of liquefaction, which could be of increasing risk as groundwater levels rise in this area.	The pressures imposed on the subgrade by the station platform and track structure are usually not significant enough to be affected by liquefaction. The main concern is saturation of the subgrade soils. As they become saturated they become unstable and will not provide the compressive strength needed to support these facilities. Alternative support systems must be incorporated to minimize settlement potential.	**Reinforcement:** The tracks can be supported on reinforced concrete slabs to reduce the potential for settlement. Drilled piers can be incorporated within the station platform to provide additional support. Regional adaptation strategies focusing on shoreline protection will be appropriate to address this vulnerability.	New initiative / Project Planning and Design	City of Oakland, AMTRAK, UP, CCJPA.	Dependent on focus area strategy development; Long-term Inundation at 72"
	Amtrak FUNC1. Station is served by a free parking lot and there are few alternative locations to park and leave cars aside from limited on-street parking. If 73rd Avenue is closed due to flooding, pedestrians can still access the station via the pedestrian overhead bridge from the Coliseum BART station. However, parking for those using the passenger rail service may be limited at the Coliseum BART station.	Flooding at Amtrak station is likely preceded by flooding at Coliseum parking lots.	**Expand RTEMP Members (event response)** Provide sufficient warnings and information, and movement restrictions to the Amtrak parking lot to direct drivers to parking at other (nearby) Amtrak stations. Expand RTEMP to include CCJPA (Capitol Corridor) and ensure implementation and coordination of emergency response plans. **Physical strategies (long term planning)** Account for station access in prioritizing adaptation responses that reduce inundation risk in the Amtrak parking areas, in order to preserve transit access.	Preventative - the RTEMP is updated annually and agencies coordinate changes and regular training events.	RTEMP members: MTC, Caltrans, CHP, WETA, BART, AC Transit, ACE, City of Oakland, AMTRAK, UP, CCJPA.	Start incorporating SLR considerations into next major update of RTEMP (last one done in 2008).

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Oakland Coliseum Amtrak Station	**Amtrak FUNC2**. The function of the station will be affected by a disruption to commercial power supplies as the electronic notification system, lighting, and monitoring cameras that are part of the operations of this station will be disrupted, making the station unsafe for users at night and inconvenient in general due to lack of train information and status updates.	Power loss to station likely accompanied by power loss to Amtrak communications, disrupting service. Station and service closure likely.	Provide backup electric power to station as needed. Co-ordinate with PG&E over their plans to maintain service during SLR induced flooding scenarios. Close station and redirect passengers and supporting transportation service to other Amtrak stations. Expand RTEMP to include CCJPA (Capitol Corridor) and ensure implementation and coordination of emergency response plans.	Emergency and Hazard Planning	RTEMP members: MTC, Caltrans, CHP, WETA, BART, AC Transit, ACE PG&E, City of Oakland, AMTRAK, UP, CCJPA.	Start incorporating SLR considerations into next major update of RTEMP (last one done in 2008). Start /continue talks with PG&E regarding their plans for supply continuity in SLR related flooding
	Amtrak FUNC3. Service to and from the station would be affected by a disruption to commercial power supplies, as the signal system is critical to the safe operation of the rail service. Although the signal system has battery backups that can last a few hours, and then there are protocols in place for manual signally by railroad staff, these are only short-term solutions.					
	Amtrak FUNC4. If the rail track in the vicinity of the Coliseum is flooded or damaged, the intercity passenger rail service will be disrupted and the Coliseum Amtrak station will not be in service. An alternative bus bridge service could be set up to get passengers around the disrupted rail track and station, however this is only a short-term solution.	Alternative modes to and from Coliseum station include automobile (provided parking is available), BART Fremont and Dublin lines (provided station is accessible), and bus service (provided local streets are accessible).	**Expand RTEMP Members (event response)** Expand RTEMP to include CCJPA (Capitol Corridor), City of Oakland and Amtrak to ensure implementation and coordination of emergency response plans.			
	Amtrak FUNC5. Due to the linear connectivity of rail track, a disruption to any rail segment within the Capitol Corridor would impact passenger service. There is no realistic alternative route for the service, or in fact for goods movement, if this segment of rail track is damaged or disrupted.	Local-access goods movement routes could include BNSF or UP Class I routes in the San Joaquin Valley via Stockton and Martinez. Through-moving goods movement route would continue north from Stockton. Through-moving passenger trips could avoid the section on the Amtrak San Joaquin route. Local service to San Jose may be served by ACE rail to/from Stockton.				
	Amtrak FUNC6. There are no alternative rail transit options providing intercity service from San Jose to Sacramento, and the state highway I-880 that could provide an alternative route for car or bus service is vulnerable to the same sea level rise and storm event impacts as this segment of rail track.	Alternate automobile and bus routes include I-880, I-580, I-680 (to SR24 for local travel).	Ensure RTEMP and emergency service plans are in place and tested.	Emergency and Hazard Planning	CCJPA, AC Transit, Amtrak, Caltrans, CHP, City of Oakland, UP, CCJPA.	

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BART Oakland Airport Connector Underpass	**BART OAC PHYS1:** The OAC has a portion that is in a tunnel below grade and vulnerable to increased flooding due to storm events and sea level rise. Sump pumps were most likely designed to manage 100-year storm events, current groundwater intrusion or rainfall runoff, but will not have the capacity to handle flows during a significant flooding events -- especially as groundwater elevations increase as sea level rises.	The tunnel has a sump pump system design (wet well) for 100 year storm event (likely fluvial only).The walls and floor of the tunnel have been waterproofed to minimize groundwater seepage; however, a small amount of groundwater seepage into the sump remains after the waterproofing (~150 gallons per day). BART and its consultants are currently coordinating with the Regional Water Quality Control Board on discharge requirements for the groundwater.	**Levee (Asset-Specific):** Construct soil levee on water side (northwest) of underpass Airport Access Road to an elevation that will eliminate exposure of flooding. Viable option only if inundation is blocked from reaching the underpass access road from the other side.	New initiative	BART	Dependent on focus area strategy development; Medium-term Exposure to 36" Inundation
BART Oakland Airport Connector Wheelhouse	**BART OAC PHYS2:** The OAC has a diesel emergency generator but it is located at grade in the wheel house.	No additional refinement provided.	**Generator Elevation:** Raise the non-water resistant equipment off the floor to prevent water contact with generator.	New initiative	BART; Dopple-Maye	Dependent on focus area strategy development; Long-term Inundation at 72"
			Ring Levee: Provide a watertight retaining wall around the Generator area with water resistant access gates. Similar in concept to containment structures around above ground tanks, with opposite intent - keep water out, rather than contained. Containment would be constructed as reinforced concrete walls with composite base slab if needed.	New initiative	BART; Dopple-Maye	Dependent on focus area strategy development; Long-term Inundation at 72"
BART Oakland Airport Connector Wheelhouse Substation	**BART OAC PHYS3:** The wheelhouse substation is at grade and was not designed to be water or salt tolerant.	No additional refinement provided.	**Berm:** A berm can be constructed around the substation to contain SLR and storm surge in the nearer term. The berm would need to include ramps to allow equipment to be replaced within the sub-station as necessary.	New initiative	BART; PG&E	Dependent on focus area strategy development; Long-term Inundation at 72"
BART Oakland Airport Connector Switch Gear	**BART OAC PHYS4:** The switchgear cabinets at the airport station are at grade and are not designed to be water or salt tolerant.	No additional refinement provided.	**Switch Gear Elevation:** Raise the non-water resistant equipment off the floor to prevent water contact with switchgear cabinets and/or water proof the cabinets with water tight doors.		BART; Dopple-Maye	Dependent on focus area strategy development; Medium-term Exposure to 36" Inundation

ASSET	VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
BART Oakland Airport Connector (OAC) General	**GOV1:** BART owns the OAC, but Dopple-Mayer will manage operations and maintenance, including sump pumps to provide drainage during storm events. The Dopple-Mayer Management Plan is in progress, but only a 20-year contract and not incentivized to consider more frequent storm events due to sea level rise. Adaptation may require coordination with Dopple-Mayer which may be out of scope with their contract.	No additional refinement provided.	**Dopple-Mayer Contract Revision:** The agency should consider reviewing the Dopple-Mayer contract to ensure that consideration for future adaptations from sea level rise and extreme weather events can be coordinated and implemented. The agency should also consider which party pays for the damage incurred from extreme weather events.	New initiative	BART; Dopple-Maye	Dependent on focus area strategy development; Medium-term Exposure to 36" Inundation
	BART OAC FUNC1: The OAC extends from the BART Coliseum Station to the Oakland International Airport and relies on existing structural shoreline protection, owned and managed by others. The system of structural shoreline protection were not designed for future storm event water levels that will occur as sea level.	If Coliseum is flooded, it is likely that OAK and OAC access will be flooded, unless adaptation strategies are implemented at OAK.	RTEMP updates should include OAC once implemented. OAC service could be replaced by bus service if access roads and OAK are minimally or not disrupted. OAC service could be replaced by routes to/from other BART stations as needed if only Coliseum station is disrupted.	Emergency and Hazard Planning	RTEMP members: MTC, Caltrans, CHP, WETA, BART, AC Transit, ACE	Start incorporating SLR considerations into next major update of RTEMP (last one done in 2008).
	BART OAC FUNC2. Flooding of the track that passes through the tunnel would disrupt services of the OAC.	Flooding near OAK would disrupt both the tunnel and at-grade OAC track segments. Flooding would hit OAK first, reducing demand for transit passage.				
	BART OAC FUNC4: The sole function of the OAC is to provide transit access to the Oakland International Airport. If operations of the airport are disrupted the OAC will not have a purpose.	Demand for OAC is reduced if passenger service at OAK is disrupted. OAC would serve to evacuate passengers and employees at airport; OAC would serve emergency workers traveling to and from the airport during emergency response, recovery and mitigation phases.	Coordinate OAC service with RTEMP to ensure efficient and safe transportation for evacuation and emergency worker access.			
	BART OAC FUNC3: There are no good alternatives to access the airport if the OAC flooded because the local streets and roads that lead to the airport will also be flooded and impassible in particular near the OAC tunnel location.	Flooding would hit OAC first, reducing demand for street travel to and from the airport.	NA - Physical mitigations at OAC are likely to reduce or eliminate flooding on ground-level transportation assets.	NA	NA	NA
	BART OAC FUNC5. Access to the OAC relies on the ongoing operation of the Coliseum BART station. Disruption to this station or the adjacent local streets and roads would inhibit passenger access to the OAC.	Likely that OAC BART will be inundated prior to Coliseum BART, reducing need for travel from Coliseum to OAC. Will need to consider regional strategies to ensure access to both stations is maintained during the same event.	NA	NA	NA	NA

CORE ASSET SPECIFIC STRATEGIES
FOCUS AREA: HAYWARD

ASSET	VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
SR-92 causeway between Toll Plaza and Mainland	**SR-92 PHYS2:** The western portion of SR-92 (west of Whitesell Road) is within the existing 100-year floodplain. Flood risk will increase in extent, depth and duration due to sea level rise in this area as it is already low lying. **SR-92 PHYS5:** A high groundwater table can damage at-grade pavement structural sections if they are constantly saturated and cause major dewatering problems for future construction.	No additional refinement provided.	**Drainage Study:** A study of the existing drainage system/capacity should be undertaken by Caltrans in collaboration with the City of Hayward and ACFCWCD in order to understand the existing capacity of the system, and to inform the drainage opportunities and constraints associated with the suite of potential physical adaptation strategies.	New initiative	Caltrans, City of Hayward, ACFCWCD	Dependent on focus area strategy development; Medium term Inundation starts at 24".
			Embankment Strengthening Armor face of embankment with rip-rap to reduce exposure to wave induced erosion.	New initiative	Caltrans, USACE	
			Levees Build engineered levees parallel to SR92, with variable habitat on the backside of the levee. Roadway remains at existing grade and ultimately below flood level fully dependent on levee structures for protection. Would provide protection of critical public transportation infrastructure, but would visually cut off road from views of adjacent wetlands. Levees would need to consider ongoing restoration efforts (such as the South Bay Salt Pond Restoration Project), and be designed to integrate into restored/restoring habitat areas. Levee designs should be adaptable to provide increasing protection over time, if practical, to address changing conditions in the surrounding area.	New initiative	Caltrans, City of Hayward, EBRPD, HARD, CADFW, BCDC, CADFW, RWQCB, USACE	
			Seawalls Build seawalls adjacent to SR92. This would take less footprint than a levee, but have no habitat value and would visually cut off the road from the wetland restoration project. Roadway remains at existing grade and ultimately below flood level fully dependent on seawall structures for protection. Appropriately separates protection of critical public transportation infrastructure from other elements and provides focused solution.	New initiative	Caltrans, City of Hayward, EBRPD, HARD, CADFW, BCDC, CADFW, RWQCB, USACE	
			Elevated Causeway Construct new elevated pile supported road section(s). New road constructed adjacent to existing road so very limited closure issues. Likely no need to move toll plaza. Following new road opening, existing road grade removed to connect habitat areas to north and south. Appropriately separates protection of critical public transportation infrastructure from other elements and provides focused solution.	New initiative	Caltrans, City of Hayward, EBRPD, HARD, CADFW, BCDC, CADFW, RWQCB, USACE	

ASSET	VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
SR-92 causeway between Toll Plaza and Mainland			**Boat-Section** Construct reinforced concrete composite roadway, at existing grade, and walls to form a water tight "boat section".(A boat section is used to protect a roadway though a low spot.) Pumps would be needed if boat-walls developed. The walls would visually cut off the road from the wetland restoration project. There may be reservations against building protective walls along this segment. A pump station is required to handle both seepage in from the outside when groundwater is high and during storm events for direct rain within the length of the depressed zone. Gutters and pumps would be designed to ensure a dry traveled way for at least 100 year storm intensities. The usefulness of the strategy, since pumps would be required, has no time limit since the pumps would operate regardless of how high the water level outside the boat section (assuming the boat section is not overtopped). Adaptability over time is possible with a phased approach. However, due to the cost of constructing a boat section, it would be designed to accommodate the most severe scenario, which would only be a difference in a few feet of wall height. The only real phasing likely to occur might be the number and/or size of pumps initially installed with greater capacity in pumping added as needed in the future	New initiative	Caltrans, City of Hayward, EBRPD, HARD, CADFW, BCDC, CADFW, RWQCB, USACE	Dependent on focus area strategy development; Medium term Inundation starts at 24".
			Pumps Evaluate installing pumps large enough to pump out water intrusion at a rate that will prevent impact on the traveled way.	New initiative	Caltrans	

ASSET	VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
SR-92 causeway between Toll Plaza and Mainland	**SR 92 GOV5:** Work along the SR-92 corridor requires coordination with a number of regulatory agencies including BCDC, CADFW, RWQCB, and USACE because of its location between tidal marshes and managed ponds. The amount of coordination necessary can delay necessary maintenance or improvements to address future storm events and sea level rise impacts. **SR92 GOV6:** Caltrans has a narrow Right-of-Way for SR-92 so any major improvements will require cooperation with adjoining property owners and managers, including the City of Hayward, EBRPD, HARD and CADFW. Adjacent property owners and managers are subject to regulatory oversight by a number of state and federal agencies due to the presence of endangered species and marsh habitat.	No additional refinement provided.	**See Caltrans GOV3:** Adaptation Strategy Coordination with Permitting Agencies: Set up a working group of relevant agencies and run a series of meetings to discuss Caltrans's potential sea level rise adaptation and risk mitigation strategies (and the importance of these strategies to maintaining regional mobility). This group should participate / join in with current collaborations working in this focus area to ensure coordination of efforts. Meetings should identify ways to streamline permitting processes (especially biological reviews) and avoid future adaptation project planning and implementation delays. A key outcome would be to determine what an overarching permitting strategy might be for projects in the SR 92 corridor to best address permitting needs in the long run. Potentially a programmatic permit solution could be developed with a 20 or 50 year timeframe that would allow large scale mitigation to occur for projects over time providing major ecological benefit and make permitting for individual projects more straight forward. It would be important to start this coordination well in advance of the planning of major infrastructure adaptation strategies, as programmatic permits take time and effort to develop. (Recent examples of successful programmatic permits include for High Speed Rail and the Small Erosion Repair Program for levees in Northern California for the Department of Water Resources. Key outcome: Establish overarching permitting strategy for adaptation solutions in project focus areas including actors, project actions, timeframes and level of detail that would be required for strategies. Engage regulatory agencies early in process and gain buy in on permitting strategy.	New initiative	Caltrans, City of Hayward, EBRPD, HARD, CADFW, BCDC, CADFW, RWQCB, USACE	Short-Term to start process which could be lengthy
	SR92 FUNC1: There is no adequate local alternatives to cross the Bay as the Dumbarton Bridge and approaches has a similar exposure and vulnerability to sea level rise and storm events as SR-92.	This functional vulnerability gives an indication of the high consequence if the asset is flooded. Alternate routes include I-80 and Bay Bridge. However, if SR-92 is inundated, I-80 is also likely inundated. Alternate modes include BART Pittsburg and Richmond lines; AC Transit (Express on San Pablo, local routes); Transit providers include AC Transit, BART, WETA and private bus shuttles.	**Update and Maintain RTEMP (event response)** Update and maintain Regional Transportation Emergency Management Plan (RTEMP) to ensure adequate user and agency information to prepare for, respond to and recover from SLR-related events. Examples include updated 511 traveler information, increased transit/ferry service, suspending or controlling route access, and transportation demand management strategies. Maintain transportation agency mutual aid agreements; Explore addition of private transit shuttles to RTEMP and mutual aid agreements.	Emergency and Hazard Planning	RTEMP members: MTC, Caltrans, CHP, WETA, BART, AC Transit, ACE	Medium term when emergency strategies might be needed for SLR closure, Inundation at 48".

ASSET	VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
	SR92 FUNC2: SR-92 carries AC Transit Route M which connects the MTC Communities of Concern of Hayward and Union City to the goods, services and jobs on the peninsula. There are no adequate alternative transit options (e.g., rail or ferry).	This functional vulnerability gives an indication of the high consequence if the asset is flooded. This vulnerability also gives an indication of the equity consequences is the asset is inundated. Alternate routes include I-80 and Bay Bridge. During periodic closure of the bridge there would likely be adequate goods and services to support MTC communities of concern in Hayward and Union City minimizing this vulnerability.	See above re. RTEMP maintenance. For example, if SR92 is closed for a significant period time due to inundation, plan for alternative automobile and bus re-routing on SR84.	Emergency and Hazard Planning	RTEMP members: MTC, Caltrans, CHP, WETA, BART, AC Transit, ACE	Medium term when emergency strategies might be needed for SLR closure, Inundation at 48".
SR 92: San Mateo/Hayward Bridge Toll Plaza (Note: Toll Plaza is above grade, but the rest of the bridge is at-grade)	**SR-92 PHYS3:** There are two 2000 fuel storage tanks kept on site at the toll plaza. They are permanent, non mobile and could be vulnerable to damage/failure resulting in contamination of Bay.	Island supporting toll plaza may be vulnerable as a result of embankment erosion.	**Relocate Tanks** Relocate tanks to an area not exposed to coastal flooding and away from sensitive habitat.	New initiative	Caltrans	Long-term Inundation at 48"
			Ring Levee: Provide a watertight retaining wall around the fuel tanks with water resistant access gates. Similar in concept to containment structures around other above ground tanks, with opposite intent - keep water out, rather than contained. Containment would be constructed as reinforced concrete walls with composite base slab if needed.	New initiative	Caltrans	Long-term Inundation at 48"
	SR-92 PHYS4: The toll plaza for SR-92 relies on electrical components that are not protected from flooding and would be damaged by salt water exposure. **SR-92 PHYS5:** Saltwater intrusion and a rising groundwater table may cause corrosion problems for metal pipes, reinforcing in concrete structures, and pump equipment that are necessary to maintain operations at the toll plaza and this segment of SR-92.	Critical life safety issues, such as maintaining lighting and communications should be addressed. Note that the toll plaza is at about the same elevation as the end of the bridge. The roadway through the length of the toll plaza slopes down only a few feet. Therefore, the elevation is about 19 to 17 feet above the current bay. This is well above any future sea level + storm water rise scenario. Toll plazas are very expensive infrastructure and moving it is not currently a feasible option.	**Waterproof Junctions:** Replace all power and communication lines using water tight conduits and fixtures. For safety lighting with exposed fixtures, replace with underwater rated fixtures and ensure they are GFCI protected.	New initiative - combine with recommended and scheduled Caltrans maintenance.	Caltrans	Long-term Inundation at 48"
Bay Trail	**Bay Trail PHYS:** Since the Bay Trail is located on levees, which are vulnerable to erosion and overtopping, the trails will erode or flood as the levees are overtopped or eroded.	No additional refinement provided.	**Trail Relocation** Evaluate alternative route that locates trail at landside shoreline, to reduce vulnerability.	Long -range planning	ABAG, Cities, Counties, Park Districts, Property Owners	Dependent on focus area strategy development;

ASSET	VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
Bay Trail	**Bay Trail GOV1:** Repairs of the Bay Trail are difficult to implement due to the trail's location on levees and along marshes due to permitting constraints, e.g., threatened and endangered species and Bay fill. Storm events and sea level rise will likely increase the need for repairs because higher water levels increase levee erosion.	No additional refinement provided.	**See Caltrans GOV3.** Development of workshops for permitting agencies (and other stakeholders) and potential formation of governance group	New initiative	Caltrans, City of Hayward, EBRPD, HARD, CADFW, BCDC, CADFW, RWQCB, USACE	Short-term
	Bay Trail GOV2: EBRPD has no regular Bay Trail preventative maintenance program, such that minor damage may be hard to repair in a timely, low-cost manner and result in serious disruptions. **Bay Trail GOV3:** EBRPD does not have plans for how to improve or maintain the Bay Trail in the Hayward Regional Shoreline in the face of future storm events and sea level rise.	No additional refinement provided.	**Preventative Maintenance:** Develop a preventative maintenance approach for the Bay Trail through a partnership with the existing landowners. Regular inspections (such as twice yearly) could indentify potential problem areas. Use an for maintenance of the Bay Trail on an ad-hoc basis, similar to the approach being used for berm repair and maintenance within the salt pond restoration areas. Within the salt pond restoration areas (Eden Landing pond complex), public access trails and connections with the Bay Trial are a priority goal. This same philosophy should extend to the Hayward Regional Shoreline Areas, and access via the Bay Trail should be considered as part of any strategy that includes flood protection elements north and south of HWY 92.	Proactive	ABAG, Cities, Counties, Park Districts, Property Owners, Salt Ponds Restoration Project, USACE	Short-term
	Bay Trail FUNC1. The stretch of Bay Trail in the Hayward Shoreline Area has no nearby alternative routes so disruption to any part of the trail disrupts the entire stretch.	Alternate routes are available in city bicycle plans although SLR-related re-routing is not specifically addressed. Example is the 2007 Hayward bicycle plan which identifies roadways such as Industrial Boulevard and Calaroga Avenue as Class II and III bikeways	**Provide traveler information for alternate routes (event response)** Provide sufficient traveler information to redirect users to alternate non-motorized routes. Would require coordination between Bay Trail manager/operator and neighboring cities of San Lorenzo, Hayward and Union City to ensure connectivity. Could potentially be addressed in RTEMP. The City of Hayward Bike Plan identifies several Class II bikeways (marked lanes) throughout the city; should ensure direct links to shoreline trail. **Develop new Class I path (long term planning)** Support development of East Bay Greenway as an alternate route. This trail would be part of a proposed greenway on BART right-of-way extending from Oakland to Fremont. The group Urban Ecology is currently working with BART to negotiate trail construction in conjunction with BART's seismic retrofit of the elevated rail lines.	Emergency and Hazard Planning /Land use planning	Bay Trail Cities of San Lorenzo, Union City, Hayward.	Dependent on focus area strategy development;

ASSET	VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
Bay Trail	**Bay Trail FUNC2.** The Bay Trail pedestrian bridge over CA-92 cannot be easily moved or rerouted.	See above. Rerouting would preclude need for pedestrian bridge at this location.	**Provide traveler information for alternate routes (event response)** Provide sufficient traveler information to redirect users to safe, marked alternate non-motorized routes. Would require coordination between Bay Trail manager/operator and neighboring cities of San Lorenzo, Hayward and Union City to ensure connectivity and adequate temporary or infrastructure safety measures. Existing Class III connections need upgrading, and SR-92 crossing . Could potentially be addressed in RTEMP. **Develop new facilities (long term planning)** See above re proposed East Bay Greenway.	Emergency and Hazard Planning /Land use planning	Bay Trail Cities of San Lorenzo, Union City, Hayward.	Dependent on focus area strategy development;

REGIONAL STRATEGIES: BAY BRIDGE

<table>
<tr><th>STRATEGY</th><th>ASSETS PROTECTED</th><th>VULNERABILITIES ADDRESSED (& vulnerability refinement)</th><th>POINT OF INTERVENTION</th><th>PARTNERS</th><th>TIMING</th></tr>
<tr><td>Shoreline Protection:
Designed structure (such as an engineered berm with rock revetment, but maximizing the use of natural elements as much as possible to maintain the link with the valuable habitats in this area) alongside road corridor to north of bridge (I80). Include active management (such as periodic placement of sediment) and restoration of wetland to help the wetlands and habitats keep pace with SLR. Any shoreline structure constructed adjacent to I80 must take into account roadway drainage that would occur during rainfall events, and consider the feasibility of collecting (and potentially treating) the roadway drainage before disposal to the Bay.</td><td rowspan="3">Core:
I80 along the north side of the Bay Bridge, I880

Adjacent:
Emeryville crescent marsh, radio beach, and other assets on the north side; potentially some south side (water flow analysis needed).</td><td rowspan="3">The north side of the Bay Bridge, over by Radio Beach, is very low with respect to the tides. The roadway adjacent to the highway was flooded during site visit (7 March 14) – it is obvious that it floods all the time since there is marsh vegetation all the way up to the HWY road embankments. The HWY itself is just a couple of feet higher.

The Bay Bridge Core Asset is vulnerable to permanent future inundation with static sea level rise. This asset is vulnerable to periodic inundation associated with 12 inches of sea level rise and a King Tide event. This asset could be temporarily inundated under existing conditions with a storm surge event greater than a 25-year recurrence interval. The adjacent habitat area and frontage road are regularly inundated by high tides under existing conditions. This regular inundation could degrade and erode the adjacent frontage road area, thereby making the Bay Bridge asset more vulnerable over time. Strategies that enhance and protect the adjacent habitats will reduce the vulnerability of the Bay Bridge in the short term, and increase the likelihood that the habitat areas can be sustainable. As sea level rise, particularly beyond 12 inches, more substantial strategies (such as an offshore breakwater or shoreline protection along the roadway) will be require

Potentially these strategies could protect all of the core and adjacent assets in the focus area depending on extent of berm)</td><td>New initiative</td><td>Caltrans, BCDC, EBRPD, BART, Caltrans</td><td>Short-term: Active management of wetlands
Short term
Radio Beach inundation at 12"

Medium term
I80 inundation at 24"</td></tr>
<tr><td>Artificial Dunes:
Construct artificial dunes for the entire length of the low-lying section north of the Bay Bridge touchdown to retain the habitat value of that area, while providing protection to the HWY.</td><td>New initiative</td><td>Caltrans, BCDC, EBRPD, BART, Caltrans</td><td rowspan="2">Sequencing of potential shoreline strategies TBD determined once TT provided feedback on potential strategies. Offshore breakwater likely to be needed in tandem with dunes.
Short term
Radio Beach inundation at 12"
Medium term
I80 inundation at 24"</td></tr>
<tr><td>Offshore Breakwater:
Construct an offshore breakwater to the north of the Bay Bridge touchdown. This would not mitigate sea level rise, but it would reduce storm surge and wave impacts, and it would provide protection to the HWY and the adjacent habitats (marsh, dunes, pocket sandy beaches) and it could provide protection to the Emeryville crescent marsh area. It could work in tandem with constructing artificial dunes too. (Likely to be needed in order to retain all of that habitat in the longer term)</td><td>New initiative</td><td>Caltrans, BCDC, EBRPD, BART, Caltrans</td></tr>
</table>

STRATEGY	ASSETS PROTECTED	VULNERABILITIES ADDRESSED (& vulnerability refinement)	POINT OF INTERVENTION	PARTNERS	TIMING
Shoreline protection: Construct a low berm or wall to separate Gateway Park south of I-80 from the maritime industrial area just to the east. This will block an inundation pathway along Burma Road that allows high tides to enter EBMUD and Port and other areas to the east and south. If Burma Road could be raised it could serve as the barrier to flooding rather than a separate berm or floodwall. This could also be an emergency access route to the Bay Bridge touchdown area during extreme high tide and/or storm surge events during earlier stages of the sea level rise time horizon.	**Adjacent:** Industrial areas east of Gateway Park that are south of I-80. These include EBMUD and the Port of Oakland. **Core:** Transbay Tube	To the south of the Bay Bridge, the water comes high up the shoreline (evident from debris line). It is an erosive shoreline with lots of armor stone. The future park needs to accommodate shoreline options to deal with storm surge. Likely it would be easiest to accommodate them with the future rehab that will come when the land is redeveloped. It will be challenging to raise grades very much. There were obvious drainage issues associated with the recent rainfall. One EBMUD building is sand bagged. There was a lot of ponded water under and around the bridges – even though it had been over 24 hours since the last rainfall. The first areas where overtopping and inundation occur are along Gateway Park, therefore this area is a critical reach to restore and protect. This area would also be overtopped and inundated by 36 " of sea level rise and King Tide, or 24 " of sea level rise and a 5-year storm surge event, or 12" of sea level rise and a 50-year storm surge event. It is important to note that inundation under storm surge scenarios would be temporary, and the inundation under a storm surge event may not be as extensive as shown on the inundation maps if additional physical processes and the duration of extreme tide levels were considered. Vulnerabilities of all assets listed to the left.	New initiative	BCDC, EBMUD, Port of Oakland, BART, Caltrans	Medium term Inundation at 48"
Natural/Engineered Protection: Redevelopment is currently planned for Gateway Park. This area should consider a combination of structural protection measures integrated with habitat elements to provide a natural aesthetic. This area experiences a significant wave climate and high potential for storm surge inundation, therefore an armored shoreline is likely necessary. The shoreline could include features at or near the existing grade, with landscape elements that incorporate high marsh and riparian habitat features that can accommodate temporary/periodic inundation by extreme tides and storm surge. To accommodate future inundation, terracing the landscape would allow for sea level rise and a manageable transitioning of Park uses and habitat types along each terrace. Additional flood protection features would need to be incorporated into the park design to protect existing structures and buildings. If existing structures can be raised during redevelopment, this should be considered.	**Adjacent:** Gateway Park, and areas inland along the south edge of I80, including Port of Oakland and EBMUD infrastructures **Core**: Transbay Tube	Need to confirm plans for sub station in relation to Gateway Park. Although this area does not exhibit a high vulnerability for permanent inundation until 24 inches of sea level rise, the high tide levels observed on the site visit highlight that this area is, and will be, vulnerable to temporary inundation by extreme tides, waves, and storm surge inundation in the more immediate future. This area will likely experience temporary inundation on a regular basis before 12 inches of sea level rise is reached.	New initiative / Project Planning and Design	BCDC, EBMUD, Port of Oakland, BART, Caltrans	Short term Inundation at 24"

REGIONAL STRATEGIES: COLISEUM

<table>
<tr><th>STRATEGY</th><th>ASSETS PROTECTED</th><th>VULNERABILITIES ADDRESSED</th><th>POINT OF INTERVENTION</th><th>PARTNERS</th><th>TIMING</th></tr>
<tr>
<td>Damon Slough Tide Gate:
Block Damon Slough just west of I-880 and install a tide gate which will still allow the slough to drain during flood events and drop its sediment load behind the barrier, but deny sea level rise to the Coliseum area. The tide gate would have to be raised periodically because of both the sediment deposition and sea level rise, but that should be a small cost overall. This concept is similar in design to the Thames Flood Barrier (on a much smaller scale), and provides some transient storage. At more advanced levels of sea level rise where gravity flow is lost, provision for pumping stormwater to a point west of I-880 will need to be considered.</td>
<td>Core: Coliseum BART Station, Coliseum BART Pedestrian Tunnel, Coliseum BART Station Traction Power Substation, Coliseum BART Station Control Room.

Adjacent: Coliseum Amtrak Station, Coliseum Areas, I-880 Bridge.</td>
<td rowspan="2">There are flooding concerns at Damon Slough. AECOM to re-run flooding model based on data provided by Alameda County to determine the contribution of riverine flooding to overall inundation of areas around coliseum. Strategies should be re-visited once AECOM completes this analysis.

All physical and functional vulnerabilities of the assets listed to the left.

Coliseum Complex PHYS1;

This area is vulnerable to 48 inches of sea level rise above MHHW, although similar vulnerabilities are also observed under existing conditions with a 100-year storm surge events. The first area to be overtopped is around Damon Slough. The full vulnerability of this area is not captured by the sea level rise inundation maps. Flooding can also occur in this area due to rainfall runoff flooding in Damon Slough and in other small tributaries.</td>
<td>New Initiative</td>
<td>Oakland-Alameda County Coliseum Authority, Oakland Coliseum Joint Venture, CalTrans, ACFCWCD, BART</td>
<td rowspan="2">Medium term
Inundation at 36"
Flooding is also associated with rainfall runoff, therefore intervention may be needed much earlier (new mapping shows flooding under existing conditions with a 10-year tide (El Nino) and a 100-year rainfall event).</td>
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<tr>
<td>Levee (or floodwall):
Construct levees adjacent to either edge of Damon Slough from east of I-880 to San Leandro St. to protect adjacent facilities and properties from future high tide levels. Mitigation for both habitat and recreation losses may need to be considered for this strategy. Does not include I-880 flood protection.</td>
<td>Core: Coliseum BART Station, Coliseum BART Pedestrian Tunnel, Coliseum BART Station Traction Power Substation, Coliseum BART Station Control Room.

Adjacent: Coliseum Amtrak Station, Coliseum Areas.</td>
<td>New Initiative</td>
<td>Oakland-Alameda County Coliseum Authority, Oakland Coliseum Joint Venture, ACFCWCD, BART</td>
</tr>
</table>

STRATEGY	ASSETS PROTECTED	VULNERABILITIES ADDRESSED	POINT OF INTERVENTION	PARTNERS	TIMING
Living Levee (Damon Slough): Use a combination of natural restoration and aesthetic levees/walls/berms along the length of Damon Slough. Also implement policy changes to prevent certain types of future land-use changes that would allow the construction of facilities vulnerable to future sea level rise. Because the footprint of walls, levees and berms would be relatively large, mitigation for loss of habitat and recreation may be required. Does not include I-880 flood proofing. This strategy will require land acquisition to be really be effective.	**Core:** Coliseum BART Station, Coliseum BART Pedestrian Tunnel, Coliseum BART Station Traction Power Substation, Coliseum BART Station Control Room. **Adjacent:** Coliseum Amtrak Station, Coliseum Areas.		New Initiative	Oakland-Alameda County Coliseum Authority, Oakland Coliseum Joint Venture, ACFCWCD, BART	
Fill Damon Slough: Fill in Damon Slough to a point just west of the I-880 Bridges in order to prevent high tide overflow in the Coliseum Area and to prevent overtopping of I-880. This would allow the I-880 crossing to be converted to an enclosed culverted battery or similar that provides adequate drainage from upland flooding. Habitat loss in Damon Slough could be mitigated offsite. Stormwater drainage that currently ends in Damon Slough would need to be rerouted and/or reconveyed to a point west of I-880. These reroutes would need to consider future water levels so as to maintain gravity flow. Where gravity flow is not possible, pumping systems may need to be considered. Sediment deposition and/or collection within the drainage system will need to be considered as part of this strategy.	**Core:** Coliseum BART Station, Coliseum BART Pedestrian Tunnel, Coliseum BART Station Traction Power Substation, Coliseum BART Station Control Room. **Adjacent:** Coliseum Amtrak Station, Coliseum Areas, I-880 Bridge.	All physical and functional vulnerabilities of the assets listed to the left. The property reclaimed/gained from filling of Damon Slough will be of high value offering potential means to offset costs. However, the County strongly recommends against taking the slough underground as it experiences significant sediment deposition – and this is a big part of the flooding issues, or what can make it worse. Damon Slough is where this system flattens out, and this is where any sediment in the system tends to drop out.	New Initiative	Oakland-Alameda County Coliseum Authority, Oakland Coliseum Joint Venture, CalTrans, ACFCWCD, BART	Medium Inundation at 48" Flooding is also associated with rainfall runoff, therefore intervention may be needed much earlier (new mapping shows flooding under existing conditions with a 10-year tide (El Nino) and a 100-year rainfall event).

STRATEGY	ASSETS PROTECTED	VULNERABILITIES ADDRESSED	POINT OF INTERVENTION	PARTNERS	TIMING
Living Levee ((Bay Farm Island): Construct a living levee/living shoreline park along the waterfront to provide protection from sea level rise and storm surge, while maintaining a natural aesthetic. For developed waterfront in the areas west of Doolittle Drive and north of Swan Way, this strategy may require property acquisition. In addition, the footprint of levees and walls may require mitigation for loss of habitat. It is assumed that recreation features could be incorporated readily into this strategy.	MLK Regional Shoreline/Bay Farm Island/MLK Jr Regional Park	All physical and functional vulnerabilities of the assets listed to the left.	New Initiative	BCDC; all permitting agencies; Alameda County, ACFCWCD	Short term MLK inundation at 12": later for core assets
Elmhurst Creek Tide Gate: Block Elmhurst Creek west of I-880 at approximately Edgewater Drive and install an "intelligent" tide gate that will still allow the creek's drainage basin to empty during flood events and drop its sediment load behind the barrier, but deny sea level rise high tide events to the Coliseum area. At normal tides the gate would be open so that intertidal habitat would not be lost. This strategy would be managed adaptively so that the tide gate might be raised periodically because of both the sediment deposition and sea level rise. At more advanced levels of sea level rise where gravity flow is lost, provision for pumping stormwater to a point west of the closure will need to be considered.	Coliseum Area and I-880	All physical and functional vulnerabilities of the assets listed to the left.	New Initiative	BCDC; all permitting agencies; Alameda County, ACFCWCD, BART	Medium term inundation at 36-48". Flooding is also associated with rainfall runoff, therefore intervention may be needed much earlier

STRATEGY	ASSETS PROTECTED	VULNERABILITIES ADDRESSED	POINT OF INTERVENTION	PARTNERS	TIMING
San Leandro Creek Tide Gate: Block San Leandro Creek north of Hegenberger Road and install an automatic tide gate that would allow the area to drain during flood events and drop its sediment load behind the barrier, but deny extreme high tide events to the area upstream of Hegenberger Road. The tide gate would have to be raised periodically because of both the sediment deposition and sea level rise. At more advanced levels of sea level rise where gravity flow is lost, provision for pumping stormwater to a point north and west of the closure will need to be considered.	Office and Light Industrial Areas, I-880, Hegenberger Road, 98th Avenue	All physical and functional vulnerabilities of the assets listed to the left.	New Initiative	BCDC; all permitting agencies; Alameda County, ACFCWCD	Short term inundation at 12". Flooding is also associated with rainfall runoff, therefore intervention may be needed much earlier
Levee with integrated Bay Trail: Raise the Bay Trail (through the construction of a berm or levee structure) to provide a hydraulic barrier to the east throughout the Coliseum Focus Area. In most cases the existing Bay Trail provides a good foundation for adding a lift of impermeable base material. An investigation of the current subsurface materials would be warranted to identify substandard materials or areas allowing high rates of groundwater flow. This strategy could be especially effective in bridging the gaps between the three proposed tide closures between Damon Slough and San Leandro Creek. The strategy could consist of a combination of conventional levee design and living levee design that incorporate not only the recreational trail amenities but also enhance habitat values along the corridor. This strategy could be tied in with the living levee strategy designed to the east side of Bay Farm Island and the Oakland Airport.	Everything east of the Trail	All physical and functional vulnerabilities of the assets listed to the left.	New Initiative	BCDC; all permitting agencies; Alameda County, EBRPD, ACFCWCD	Short term inundation at 12". Flooding is also associated with rainfall runoff, therefore intervention may be needed much earlier

REGIONAL STRATEGIES: HAYWARD

STRATEGY	ASSETS PROTECTED	VULNERABILITIES ADDRESSED (& vulnerability refinement)	POINT OF INTERVENTION	PARTNERS	TIMING
Marsh Management: Cooperative Landward Retreat: A collective strategy should be considered to assess how the marshes and ponds North of SR 92 can be managed and maintained over time. Currently this complex is managed by numerous public agencies that provide a combination of flood control, wildlife habitat, recreation, and wastewater treatment. If this larger complex is managed more collectively, shifting uses could be considered over time between the smaller individual complexes. Over time, protective measures and habitat goals could be adapted to respond to rising sea level and work toward the best and highest use of the land at that time. Incremental retreat from the existing shoreline and restoration efforts could also encourage high marsh development and increase the longevity of the marsh habitat. This approach would entail establishing the primary line of defense for flood protection landward for much of the area (either by maintaining existing landward berms, or by constructing more substantial flood protection berms). Marshes and mudflats that are outboard of this line of defense would be allowed to transgress landward naturally with rising sea levels. Critical infrastructure such as the landfills and wastewater treatment plants may require that portions of the existing bayfront berm alignment be maintained and reinforced. This approach would allow tidal marshes to naturally reduce wave heights reaching the landward levee thereby reducing flood and erosion risks and potentially the height to which levees must be raised to provide adequate flood management. Over time, these outboard marshes may drown if they cannot keep pace with sea level rise, thereby reducing their wave and flood protection potential. The ability of the marshes to keep pace with sea level rise should be monitored so that additional flood protection elements can be considered and implemented, if required.	**Adjacent:** Triangle Marsh (North of SR-92) Cogswell Marsh (North of SR-92) Hayward Marsh (North of SR-92) HARD Marsh (North of SR-92) Salt Marsh Harvest Mouse Preserve (North of SR-92)	This complex becomes vulnerable with just 12" of sea level rise -- and also under existing conditions, as a storm surge event with a 10-year recurrence interval (typical during a strong El Nino winter) can result in overtopping of many of the berms. Overtopping of the berms could cause erosion and eventually degradation of the berms, which could then exacerbate conditions at more inland ponds. The vulnerabilities in this complex will increase over time, with the functional use of the complex compromised at 24 inches of sea level rise without any intervention. Oliver Salt Ponds vulnerabilities	Proactive	Hayward Area Recreation and Park District (HARD), East Bay Regional Parks District (EBRPD), HPSA, BCDC	Short term Inundation at 12" to 36"

STRATEGY	ASSETS PROTECTED	VULNERABILITIES ADDRESSED (& vulnerability refinement)	POINT OF INTERVENTION	PARTNERS	TIMING
Maintain Existing Shoreline Alignment This strategy would be to maintain the current shoreline alignment and associated habitat values for as long as is practical. Currently this complex is managed by numerous public agencies that provide a combination of flood control, wildlife habitat, recreation, and wastewater treatment. To maintain the existing shoreline (aka 'holding the line'), the bayside berm crest elevation would need to be raised to maintain existing levels of protection. This would require berm maintenance to keep pace with sea level rise. Although maintenance of the bayside berm could maintain the current mixture of uses in the near term, this measure may not work indefinitely as water level management within portions of the complex may become more difficult as sea levels rise. In the long-term, this outer berm could be surrounded on all sides by open water (as the marshes 'drown'), resulting in berms that will be more vulnerable to erosion and require increased long-term maintenance. In addition, as many of the berms are made of bay mud using local borrow material, there may be a maximum height to which the berms can be constructed (limited by geotechnical stability and availability of local borrow material). In the long-term, improving and maintaining the bayward berms may not be cost-effective, as rising sea levels (and subsequent marsh drowning) would eventually result in the levees becoming "peninsulas" that would be surrounded on all sides by open water, leaving them vulnerable to damage from wind-wave erosion and subject to increased long-term maintenance costs.	**Adjacent:** Triangle Marsh (North of SR-92) Cogswell Marsh (North of SR-92) Hayward Marsh (North of SR-92) HARD Marsh (North of SR-92) Salt Marsh Harvest Mouse Preserve (North of SR-92)	This complex becomes vulnerable with just 12" of sea level rise -- and also under existing conditions, as a storm surge event with a 10-year recurrence interval (typical during a strong El Nino winter) can result in overtopping of many of the berms. Overtopping of the berms could cause erosion and eventually degradation of the berms, which could then exacerbate conditions at more inland ponds. The vulnerabilities in this complex will increase over time, with the functional use of the complex compromised at 24 inches of sea level rise without any intervention. Oliver Salt Ponds vulnerabilities	Proactive	Hayward Area Recreation and Park District (HARD), East Bay Regional Parks District (EBRPD), HPSA, BCDC	Short term Inundation at 12" to 36"
Agency Shoreline Protection Coordination: Any protection efforts for the HWY92 bridge may impact ongoing existing efforts in this area. Coordinate with ongoing existing shoreline protection efforts (mainly involving berms, levees and salt-pond restoration) of agencies such as the Army Corps of Engineers, California Fish and Game, the Coastal Conservancy, Alameda County Flood Control and Water Conservation District, Union Sanitary District, and the Hayward Area Shoreline Planning Agency (HASPA). HASPA could take a lead role with the various agencies in coordinating a collaborative shoreline management plan. It is noted that salt-pond restoration projects South of SR-92 are taking sea level rise into consideration	**Adjacent:** Eden Landing Ecological Reserve (South of SR-92) Oliver Brothers North Salt Pond (North of SR-92),	Eden Landing and Oliver Brothers vulnerabilities	Opportunistic - Capital Improvement	Army Corps of Engineers, California Fish and Game, the Coastal Conservancy, Alameda County Flood Control and Water Conservation District and Union Sanitary District, BCDC, Caltrans	Short term Inundation at 24"

STRATEGY	ASSETS PROTECTED	VULNERABILITIES ADDRESSED (& vulnerability refinement)	POINT OF INTERVENTION	PARTNERS	TIMING
Temporary Bayfront Berms: Maintenance of bay-front berms until marshes behind them develop, followed by natural erosion of berms over time. Temporarily maintaining the berms until marsh establishes will maintain wave protection for all inland assets. In the short term, the berms will provide this protection, and in the longer term the established marshes will provide this protection.	**Adjacent:** Oliver Brothers North Salt Pond (North of SR-92), Industrial sites West of Industrial Blvd (North of SR-92); Hayward Interpretation Center	The quality of natural habitat north of SR-92 has been deteriorating, and there is a preference for shoreline protection strategies that also achieve habitat restoration and public access maintenance. If the berms are not maintained and they are allowed to erode, the marsh will likely not establish and it will instead erode due to wave and tidal action. This will put increased pressure on the next landward flood defense, and it will result in open water/mudflat habitat instead of marsh habitat which would impact species distribution and endangered species protection efforts. Eden Landing PHYS2, Oliver Salt Ponds PHYS	Routine Operations/ Maintenance	Hayward Area Recreation and Park District (HARD), East Bay Regional Parks District (EBRPD), BCDC	Short term Inundation at 24"
Levee Improvements: Strengthen levee around zig-zag shaped Mt. Eden Creek. The existing levees are not engineered berms and should be strengthened and raised to provide protection to future development in this area. New material could be added to a prepared surface and, taking settlement into account, raising the crests 2-3 ft. This could be done for the entire length of Zig Zag creek between the bayfront and Eden Landing Road.	**Adjacent:** Industrial areas; Future development.	Vulnerabilities of industrial assets	New initiative	Hayward Area Recreation and Park District (HARD), East Bay Regional Parks District (EBRPD), HPSA, BCDC	Short term Inundation at 24"
Berm with integrated Bay Trail: Reinforce and raise the berm on which the Bay Trail is located (or re-route the Bay Trail on a more landward berm more suitable to be raised and enhanced if necessary) to provide a hydraulic barrier to the east throughout the Hayward Focus Area. In most cases the existing Bay Trail berm provides a good foundation for adding a lift of impermeable base material. An investigation of the current subsurface materials would be warranted to identify substandard materials or areas allowing high rates of groundwater flow. Increasing the height of the berm will also increase its width, therefore there may be impacts to surrounding habitats. It is recognized that there will be trade-offs associated with raising the berm and integrated Bay Trail and protecting it in place rather than re-routing the Bay Trail to a more inland location. The berm with the integrated Bay Trail alignment would be part of the overall flood defense of this area, assisting in providing multiple lines of defense. The berm could be raised in place, or realigned and strengthened, and both strategies would have similar trade-offs. As an added measure, the berm with the integrated Bay Trail could be rerouted to the west of the Hayward Shoreline Interpretive Center to protect that facility as well.	**Adjacent:** Oliver Brothers North Salt Pond (North of SR-92), Light industrial properties south of SR 92. Most marsh units north of 92 would be protected.	Oliver Salt Ponds PHYS	New initiative	BCDC, East Bay Regional Parks District (EBRPD)	Short term Inundation at 12-36" depending on location

AGENCY SPECIFIC STRATEGIES: BART

VULNERABILITY TYPE	VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
Informational	**BART INFO1 :** Asset engineering details is available as PDFs from an electronic repository. Specialized knowledge of the asset's history is however required to reconstruct the condition of the asset, by combining information from AS BUILT drawings from relevant capital improvement projects with original design documents. Some drawings are available in CAD format upon request.	While as-built drawings and technical specifications are available in digital format, institutional knowledge regarding asset condition and history are not. Additionally, most of the existing as-built data is available in PDF format, but would be more useful if it was available in CAD format. [Is the PDF data stored in a searchable database?]	**Asset Database:** The agency would update current asset management database with appropriate fields to enable attachment of as-built design documents, and data on asset condition and history. The database would need to facilitate collection and storage and retrieval of asset condition and history data. Asset managers and maintenance personnel would input this data so it is available to others in the agency. The database would provide as-built documents in both PDF and original CAD format when feasible. This would need to become part of any formal BART reporting procedure required of engineers and other staff to ensure it was maintained.	Agency specific	BART	Short-term
Informational	**BART INFO2 :** Information on asset condition is institutionalized knowledge held by maintenance personnel. There are some datasets such as OCC logs, maintenance/inspection reports that have an indication of asset condition but these do not always provide a clear understanding of existing condition.	Asset condition information is necessary for a wide range of planning purposes, including climate adaptation planning. While this information is recorded by maintenance personnel, it is not in a format that others can access. To ensure effective adaptation planning, mechanisms need to be created to facilitate the transfer of asset condition information to different divisions within the agency.	**Improved Asset Condition Data Collection:** As part of the asset database strategy described above, the agency would need to develop data collection mechanisms that record asset condition information in a format useful to both maintenance and non-maintenance personnel. An asset database that could accommodate different data in-putters and end users would be beneficial.	Agency specific	BART	Short-term
Informational	**BART INFO3:** There is a general lack of knowledge or understanding in the region about how sea level rise will affect the groundwater table and how changes in groundwater levels or salinity may affect exposure to assets (example: structural foundations, exposed electrical/mechanical equipment).	As sea levels rise local groundwater hydrology will be altered. The primary vulnerabilities associated with these changes are drainage issues and saltwater intrusion. Drainage problems and prolonged exposure to saturation soils could cause a variety of structure and operation issues for BART assets including damage to foundations and other structures. Saltwater intrusion could cause corrosion of metal infrastructure. Saturated soils could also pose increase the liquefaction hazard to BART assets.	**Groundwater and Saltwater Intrusion Modeling:** BART and other agencies would partner with appropriate (local?) academic institutions to start research to better understand the impact sea level rise would have on local groundwater hydrology. The research would provide data applicable to drainage, saltwater intrusion, and seismic hazard. The data would be used by engineers and planning staff to better evaluate asset vulnerability.	New initiative	BART, CalTrans, BCDC, USGS, academic institutions	Short-term to start as research could take time
Informational	**BART INFO1:** All information relating to the Transbay Tube (TBT) is Security Sensitive Information (SSI), which limits the access to those outside of BART that maybe necessary for understanding vulnerability and risk.	Because of SSI requirements, vulnerability assessment and adaptation strategy development for SSI assets is more difficult. Due to these difficulties there is a risk that climate vulnerability and adaptation strategy development will not be as effective for SSI-related assets.	**SSI Specific Adaptation Process:** Due to the SSI requirements, it may be necessary to conduct special climate vulnerability assessment and adaptation strategy development processes. This could include special SSI asset meetings and documents. Efforts should be made to ensure that the SSI status does not create a barrier to effective climate adaptation planning.	Agency specific	BART	Short-term

VULNERABILITY TYPE	VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
Governance	**BART GOV1:** Use changes, upgrades, or retrofits that extent beyond the BART Right-of-Way will require coordination with adjacent property owners and asset managers. In highly developed portions of the BART system, or where long stretches of BART assets are vulnerable, the number of adjacent property owners and asset managers could be large, and coordination efforts could be challenging.	No additional vulnerability refinement provided.	**Adaptation Coordination Program:** The agency should identify key adaptation strategies that would require coordination with adjacent property owners and property managers well in advance of the strategy being developed. The agency should then develop a stakeholder coordination process to provide information on the potential threat of SLR (leveraging existing ART information sources) and discuss implementation needs with relevant owners and managers. The process could include meetings, development of multiple-stakeholder plans. The process should identify physical, management, legal, and financial considerations of strategy implementation.	New initiative	BART	Ongoing
Governance	**BART GOV2:** Without a regulatory mechanisms or requirement, planning to improve BART system climate resilient will be self driven. Resources (including financing) to consider and address climate change will be prioritized if BART's upper management recognizes	If climate change resiliency is not a formal priority of the agency, then adequate resources will not be devoted to climate adaptation initiatives.	**Climate Change Risk Register Requirement:** BART's risk register details the range of risks faced by the agency. By adopting a policy to incorporate climate change as an element in the risk register, climate change resilience would become coequal with other risk management considerations.	Agency specific	BART	Short-term
Governance	**BART GOV3:** Responding to identified climate vulnerabilities (e.g., adaptation actions) must consider first and foremost the safety and operability of BART services. BART adheres to safety rules that are subject to state and federal regulations, including OSHA, CPUC and FTA oversight.	No additional vulnerability refinement provided.	**Adaptation Strategy Fatal Flaw Screening Criteria:** The agency's climate adaptation planning processes should incorporate a fatal flaw screening criteria that removes any strategy that interferes with the safety and operability of BART services from immediate consideration. However such strategies that conflict with safety and operability should be well documented and filed so that in the future information about them remains should they a) be feasible or b) be reconsidered.	Agency specific	BART	Short-term
Governance	**BART GOV4:** BART Facility Standards (BFS) requires that facility design accounts for the 100-year storm event and 500-year flood stage for critical assets, but it's not clear that impacts should be considered from extreme tides due to sea level rise.	100 - year storm event and 500-year flood stage are likely to change as sea level rises and storm frequencies and intensities increase due to climate change. If BART facility standards do not incorporate these changes, then facilities designed to the current standards may not be adequately protected.	**BART Facility Standards Update:** The agency should update its facility standards to make clear requirements for sea level rise and anticipated changes in storm frequency and intensity resulting from climate change. The agency should also review the appropriateness of 100-year and 500-year thresholds in light of likely changes in storm frequency and intensity in the future. The SLR/storm surge matrix developed as part of this project could be leveraged as part of the design criteria	Codes and Standards	BART	Short-term
Informational	**BART INFO 4:** BART does not readily have information on existing (shoreline/levee protections) or planned regional adaptations on sea level rise outside of BART's jurisdiction. It's unknown which of BART's assets may already be protected from these efforts.	BART is participating in the Adapting to Rising Tides project and is therefore connected to most of the regional work on going relating to future adaptations. BART also has access to detailed maps showing current vulnerabilities.	**Regional Adaptation Strategy group** Review organizations participating in ART project to see if there is need for a new / supplemental working group to share information regarding shoreline protection projects on a regular basis to make sure that all parties that could be impacted by future sea level rise and storm surge are coordinated on single agency and multi-agency projects.	New initiative	BART, BCDC, MTC, Caltrans, USACE, Port of Oakland, local cities, counties, multiple partners	Short-term
Governance	**BART GOV5:** Currently projects are being implemented without consideration of adaptations needs from sea level rise.	For the design or retrofit of assets with a long life span (over 25 years for example) opportunities are potentially being lost for making cost effective investment in assets if climate change impacts are not being considered at the design phase. Research has shown that $1 invested now in adaptation strategies can save $4 in recovery costs post an event.	**BART Planning Process Update:** BART should develop a requirement as part of the planning process that future climate change impacts are considered as a standard part of project design. Rather than current conditions, future conditions under a climate changed scenario should be planned for, in line with the anticipated design life of the asset. This is critical if BART wants to effectively insert adaptation on asset renewal cycles. BART could review Caltrans guidance as a template, also guidance coming from FTA and FHWA.	Project planning and design	BART	Short-term

AGENCY SPECIFIC STRATEGIES: CALTRANS

VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
Caltrans INFO2: Design and survey-grade data (such as structure elevation information) can be challenging to access and use. This type of data tends to be created on a project-by-project basis, and therefore the information is available in a project file, it is not easily accessible through a system-wide, centralized database. **Caltrans INFO3:** Caltrans has a Document Retrieval System (DRS) which is a searchable repository of the Department's project plans. However, these as-built and layout plan sheets are stored in PDF format and are not geo-referenced. The repository can be searched by location (county, route, and postmile), however, this only brings up a list of all the projects, big and small, that have occurred in that location over time. The user must then wade through a list of hundreds of projects at any particular location, and within each project folder, a list of hundreds of more plan sheets, to find the desired as-built file. The user can also search by project number to find plan sheets for a single, specific project, but most people working outside of Project Management, or without institutional knowledge, would have a difficult time identifying projects in this fashion.	No refinement provided.	**Asset Management Database (data geo-referencing):** As part of the asset management database described for the *Caltrans Gov 1 vulnerability,* develop a mandatory process that requires as-built, elevation, layout plan and other related data to be georeferenced and linked to the relevant asset component when the data is put into the system. Note that this is an overarching asset management information system issue. Responding to climate change is an additional reason why good data management is needed to target long term cost effective maintenance, but feeds in general into a general strategic maintenance program.	Agency specific	Caltrans (and BART and other agencies to share lessons learnt and best practices of developing asset management databases)	Short-Term
Caltrans INFO4: Access to the Caltrans Document Retrieval System (DRS) is not available to the public, so a request for detailed design data would have to made either through the Public Affairs office, or through the Office of Program/Project Management.	Access to Caltrans as-built documents, specifically bridge structures, became much more restrictive after 9/11. However, on a case by case (asset specific) basis, the procedure is straight forward. It does usually involve a formal request and can take a few days to a week. However, if working on a Caltrans project, the Caltrans liaison will provide any project related documents quickly without going through the formal request process. For a project such as this, based on inter-agency courtesy, Caltrans would most likely assign a staff from their Local Assistance Office to provide any requested documents. Although this may have been an issue for the BCDC project (?) the CT is not sure if this is a priority vulnerability as presuming it is Caltrans staff and their consultants who will have access to the DRS that need detailed design data for developing adaptation strategies.	**Documentation access for select organizations/agencies** Caltrans presumably can make it as easy as they decide to for people to access their documents. All of their maintenance and as-built records are now available in PDF format, so searching for and providing available documents for a specific asset, especially bridges, should not be an issue. The DRS is linked to as asset management database (as per strategy for Caltrans Gov 1. If there are a limited number of organizations involved in regional planning than need access to Caltrans documents without Caltrans staff being involved then perhaps special privileges to access the data through a site visit could be granted.	Agency specific	Caltrans	Short-Term

VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
CalTrans GOV1: Institutional knowledge housed within certain staff or departments outside of Planning can make it challenging to understand vulnerability and risk. Project managers and engineering staff are primarily funded to support the delivery of transportation improvement projects, with less of a formal mechanism to provide input on planning efforts like adaptation planning projects.	Caltrans engineering staff have detailed asset-specific data and knowledge that would be valuable to climate adaptation planning initiatives but such information is not documented in a readily available format to be used be Planning staff.	**Asset Management Database Development:** Develop an online asset management database to collect and store asset specific data particularly relevant to climate adaptation planning. The agency would need determine what information is valuable for climate adaptation initiatives. This would have to be defined for each asset type. The database would be populated by engineering staff at regular intervals as an asset undergoes upgrade or O&M. The Planning staff would utilize the data for long-term asset planning. In particular a mechanism would be set up to collect information related to weather related events, such as flooding caused by heavy rainfall. Details relating to cost and type of repair or mitigation needed, length of time of disruption etc. would be recorded. This would need to become part of any formal CalTrans reporting procedure to ensure it was maintained. Assets known to be vulnerable to SLR would be added to the database first and engineering staff requested to add details on new work.	Agency specific	**CalTrans:** [Engineering staff, project managers, Planning staff]	Short-Term
Caltrans GOV2: Maintenance costs for most assets are fairly typical and not excessive; however overall agency resources are not adequate to achieve all of the maintenance needed and therefore how funds are expended have to be prioritized.	Caltrans has had a program in place for decades of a maintenance prioritization, proactive and preventative maintenance, life cycle and functional obsoleteness to compare continuing maintenance with major rehab or replacement. SLR and storm surge related impacts may change the timing of when major rehab as opposed to on going maintenance of existing structure may be appropriate.	**Sea Level Rise Guidance Enhancements:** Caltrans currently has sea level rise guidance in place for future project planning. The guidance calls for sea level rise to be considered within project design if the project location and lifespan would likely expose the infrastructure to sea level rise. The agency should extend this guidance to also cover rehabilitation projects for vulnerable existing assets and consider future climate change impacts in to deciding the timing of functional obsoleteness, and/or to eliminate risk from a SLR or storm surge impact. The agency should also consider the cost-benefit of design alternatives that would provide protection to the sea level rise hazard. The guidance should further develop guidance related to climate change-induced storm surge.	Codes and Standards	Caltrans, MTC	Short-Term
Caltrans GOV3: Regulatory oversight can be lengthy, in particular obtaining a biological opinion if necessary. A Biological Opinion can take up to 18 months. To obtain all the necessary permits that could be required for significant work in this area could take 2-3 years, e.g., from San Francisco Bay Permit (BCDC), Section 404 (USACE), 401 Certification (RWQCB), Biological Opinion (USFWS), CESA compliance (CDFW).	While this is time consuming issue and therefore expensive, the need for regulatory oversight is unlikely to go away even for climate adaptation projects. Given the long time scale of onset of sea level rise awareness of this impact on the timing of getting work implemented needs to be factored into planning processes.	**Adaptation Strategy Coordination with Permitting Agencies:** Set up a working group of relevant agencies and run a series of meetings to discuss Caltrans's potential sea level rise adaptation and risk mitigation strategies (and the importance of these strategies to maintaining regional mobility). This group should participate / join in with current collaborations working in this focus area to ensure coordination of efforts. Meetings should identify ways to streamline permitting processes (especially biological reviews) and avoid future adaptation project planning and implementation delays. A key outcome would be to determine what an overarching permitting strategy might be for projects in the SR 92 corridor (in particular) to best address permitting needs in the long run. Potentially a programmatic permit solution could be developed with a 20 or 50 year timeframe that would allow large scale mitigation to occur for projects over time providing major ecological benefit and make permitting for individual projects more straight forward. It would be important to start this coordination well in advance of the planning of major infrastructure adaptation strategies, as programmatic permits take time and effort to develop. (Recent examples of successful programmatic permits include for High Speed Rail and the Small Erosion Repair Program for levees in Northern California for the Department of Water Resources. Key outcome: Establish overarching permitting strategy for adaptation solutions in project focus areas including actors, project actions, timeframes and level of detail that would be required for strategies. Engage regulatory agencies early in process and gain buy in on permitting strategy.	Project Planning and Design	BCDC, USACE, RWQCB, USFWS, CDFW, Caltrans, MTC, NMFS, appropriate City	Short-Term to start process which could be lengthy

VULNERABILITY	VULNERABILITY REFINEMENT	STRATEGY	POINT OF INTERVENTION	PARTNERS	TIMING
Caltrans GOV4: Caltrans operated drainage systems ultimately discharge to Alameda County Flood Control and Water Conservation District (ACFCWCD) or city storm water and flood control assets. Both ACFCWCD and the city have limited financial resources for repairs, upgrades, and retrofits of flood control and storm water infrastructure. Although the Caltrans hydrology unit works with ACFCWCD and the City of Oakland to coordinate on drainage and flood control, how the two agencies would share planning or funding for future upgrades is unknown. The capacity of this system to continue functioning as the Bay rises is unknown, and will likely vary geographically.		**Increase coordination between agencies:** Alameda County Floor Control and Water Conservation District and Caltrans both maintain existing storm water models. If practical, these models should be integrated in order to assess the capacity of the system to continue functioning with sea level rise, and to assess the benefits and/or impacts of adaptation strategies to the storm water drainage systems. Consideration must also be given to water quality concerns, particularly where roadway drainage outfalls are located near habitats areas. If the storm water models cannot be integrated, this issue should be noted and addressed on a case-by-case basis as adaptation strategies are identified, designed and implemented.	New initiative	Caltrans, ACFCWCD, MTC	Short-term to initiate discussions

Appendix D

Qualitative Assessment of Strategies

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Appendix D contains full results of the qualitative assessment described in Section 4.3.2.

Qualitative evaluation – Informational and Governance Strategies

This section provides documentation of using the evaluation criteria on shortlisted Informational and Governance Strategies in a 'qualitative' way. Where quantitative data was readily available (e.g. from the data collection exercise) this data was noted to help inform the scoring. We have not however looked up MTC model tables, nor done any GIS analysis. For some of the costing we have made gross ball park assumptions (e.g. cost of levee either side of SR92 would be very high).

Groundwater and saltwater intrusion modeling (INFO)
Bay Bridge and Coliseum
BART and other agencies would partner with appropriate academic institutions to research the impact sea level rise on local groundwater hydrology. The research provides data applicable to drainage, saltwater intrusion, and seismic hazard. The data would be used by engineers and planning staff to better evaluate asset vulnerability.

Drainage study (INFO)
Hayward SR-92
A study of the existing drainage system/capacity. Caltrans in collaboration with the City of Hayward and ACFCWCD. Understand the existing capacity of the system, and inform the drainage opportunities and constraints associated with the suite of potential physical adaptation strategies.

BART planning process update (GOV)
This will be an overarching framework that can support the other information and governance strategies. BART should develop planning process requirement to consider future climate change impacts as a standard part of project design. Rather than current conditions, future conditions under a climate changed scenario should be planned for, in line with the anticipated design life of the asset. This is critical if BART wants to effectively add adaptation into asset renewal cycles. BART could review Caltrans guidance as a template, also guidance coming from FTA and FHWA.

Caltrans Sea level Rise Guidance Enhancements (GOV)
Caltrans has sea level rise guidance for future project planning. The guidance calls for sea level rise to be considered within project design if the project location and lifespan would likely expose the infrastructure to sea level rise. Caltrans should: (1) extend this guidance to cover rehabilitation projects for vulnerable assets; (2) consider future climate change impacts in deciding the timing of functional obsolescence; (3) consider future climate change impacts to eliminate risk from SLR or storm surge impact; (4) consider sea level rise hazard protection design alternatives costs and benefits; and (5) consider climate change-induced storm surge risks.

Coordinate with permitting agencies around SR-92 (GOV)
Hayward SR-92
Caltrans lead a multi-agency working group to participate in a series of meetings to discuss potential sea level rise adaptation and risk mitigation strategies (and the importance of these strategies to maintaining regional mobility). This group should participate / join in with current collaborations working in this focus area to ensure coordination. Meetings should identify ways to streamline permitting processes (especially biological reviews) and avoid future adaptation project planning and implementation delays. A key outcome would be to determine what an overarching permitting strategy might be for projects in the SR 92 corridor to best address permitting needs in the long run. Potentially a programmatic permit solution could be developed with a 20 or 50 year timeframe that would allow large scale mitigation to occur for projects providing major ecological benefit and make permitting for individual projects more straightforward. It would be important to start this coordination well in advance of the planning of major infrastructure adaptation strategies, as programmatic permits take time and effort to develop. (Recent examples of successful programmatic permits include for High Speed Rail and the Small Erosion Repair Program for levees in Northern California for the Department of Water Resources. Key outcome: Establish overarching permitting strategy for adaptation solutions in project focus areas. Strategy identifies actors, project actions, timeframes and level of detail that would be required for strategies. Engage regulatory agencies early in process and gain buy in on permitting strategy.

Inter-Agency Coordination (Connected infrastructure) (GOV)
Bay Bridge Touchdown
Caltrans develop a working group to work collaboratively on climate change-related infrastructure vulnerabilities. Address changes to operations, decision making, and funding. Planning and implementation of climate change adaptation and risk. Mitigation strategies requires coordination between multiple agencies. The working group should include BATA, Caltrans, the City of Oakland, and the city of Emeryville.

Comparison of Scores across Strategies

	Proposed Criteria	Groundwater and saltwater intrusion modeling (Bay Bridge and Coliseum)	SR-92 drainage study (Hayward)	BART planning process update (Agency Specific)	Caltrans Sea level Rise Guidance Enhancements (Agency specific)	Caltrans coordination with permitting agencies around SR92 (Hayward)	Inter-agency coordination at the Bay Bridge Touchdown (Bay Bridge)
	Economy						
1	Marginal capital/program cost of adaptation strategy	+	+	++	+	++	++
2	Annual operating and maintenance costs of adaptation strategy	Neutral	Neutral	+	Neutral	+	+
3	Duration / life span of strategy	++	NA	++	NA	++	++
4	Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes	+	++	++	++	+	+
5	Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy. Quantitative evaluation will include changes in regional travel.	++	+	++	++	+	++
6	Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel delay.	TBD	TBD	TBD	TBD	TBD	TBD
	Social /Equity						
7	Social Co-benefits (homes protected) [Assessed as indirect benefit for governance and information / planning strategies]	+	+	NA	NA	+	+
8	Social Co-benefits (jobs protected) [Assessed as indirect benefit for governance and information / planning strategies]	+	+	NA	NA	+	+
9	Amenity Co-benefits (e.g., bike trail on new levee)	NA	NA	NA	NA	NA	NA
10	Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action (and potentially preserved due to event response) Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in transit routes.	TBD	TBD	TBD	TBD	TBD	TBD
11	Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel.	TBD	TBD	TBD	TBD	TBD	TBD
	Environmental						
12	Ecological value/function	NA	NA	NA	NA	NA	NA
13	GHG emissions - Change in automobile vehicle miles traveled (VMT). : Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel and emissions.	TBD	TBD	TBD	TBD	TBD	TBD
	Governance						
14	Potential for Jurisdictional Collaboration	Neutral	Neutral	-	-	++	++
15	Funding availability	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
16	Significant regulatory or legal issues	+	+	+	+	-	+

Groundwater and saltwater intrusion modeling (INFO)
Bay Bridge and Coliseum

<table>
<tr><th></th><th>Proposed Criteria</th><th>Input Source</th><th>Notes</th><th>Scores</th></tr>
<tr><td></td><td>Economy</td><td></td><td></td><td></td></tr>
<tr><td>1</td><td>Marginal capital/program cost of adaptation strategy</td><td>AECOM/ CS / Agencies</td><td>Estimate = $500,000: This estimate includes staffing, equipment, training, conferences, etc. This metric needs best practices or examples of past grants to model ground/saltwater intrusion.</td><td>+</td></tr>
<tr><td>2</td><td>Annual operating and maintenance costs of adaptation strategy</td><td>AECOM / Agencies</td><td>Updated periodically (1-5 years).</td><td>Neutral</td></tr>
<tr><td>3</td><td>Duration / life span of strategy</td><td>AECOM / CS / Agencies</td><td></td><td>++</td></tr>
<tr><td>4</td><td>Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes</td><td>Collected Asset Data / Agencies</td><td>There is potential to make this strategy fit it with other ongoing risk assessments being conducted by academic institutions.</td><td>+</td></tr>
<tr><td>5</td><td>Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy. Quantitative evaluation will include changes in regional travel.</td><td>Travel model or PeMS 2014; Travel model output 2040
BART report</td><td><table>
<tr><th></th><th>AADT on I-80 40th and Powell</th><th>AADT on I-80 7th and 40th</th><th>I-80 Toll Plaza</th><th>I-80 Toll Plaza</th></tr>
<tr><td>AADT</td><td>241,000*</td><td>105,000*</td><td>95,054</td><td></td></tr>
<tr><td>AADTT</td><td>12,933</td><td>12,947</td><td></td><td></td></tr>
<tr><td>BART / AC Transit Transbay</td><td></td><td></td><td>197,681</td><td>9,994</td></tr>
</table></td><td>++</td></tr>
<tr><td>6</td><td>Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs.</td><td>Travel model or PeMS 2014; Travel model output 2040</td><td>Quantitative evaluation will include changes in regional travel delay.</td><td>TBD</td></tr>
<tr><td></td><td>Social /Equity</td><td></td><td></td><td></td></tr>
<tr><td>7</td><td>Social Co-benefits (homes protected)</td><td>County assessor or city parcel data</td><td>Indirect benefit based in improvements in project prioritization and infrastructure design based on this strategy.</td><td>+</td></tr>
<tr><td>8</td><td>Social Co-benefits (jobs protected)</td><td></td><td>Indirect benefit based in improvements in project prioritization and infrastructure design based on this strategy.</td><td>+</td></tr>
<tr><td>9</td><td>Amenity Co-benefits (e.g., bike trail on new levee)</td><td>AECOM</td><td></td><td>NA</td></tr>
<tr><td>10</td><td>Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action (and potentially preserved due to event response) Not used for qualitative evaluation given data needs.</td><td>MTC Communities of Concern map</td><td>Quantitative evaluation will include changes in transit routes.</td><td>TBD</td></tr>
<tr><td>11</td><td>Change in vehicle hours of delay for trips in lowest income category (compared to all income categories): Not used for qualitative evaluation given data needs.</td><td>MTC CoC and MTC Travel Demand Model</td><td>Quantitative evaluation will include changes in regional travel.</td><td>TBD</td></tr>
<tr><td></td><td>Environmental</td><td></td><td></td><td></td></tr>
<tr><td>12</td><td>Ecological value/function</td><td>AECOM / CDFG</td><td></td><td>NA</td></tr>
<tr><td>13</td><td>GHG emissions - Change in automobile vehicle miles traveled (VMT): Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel and emissions.</td><td>Travel model output 2040</td><td></td><td>TBD</td></tr>
<tr><td></td><td>Governance</td><td></td><td></td><td></td></tr>
<tr><td>14</td><td>Potential for Jurisdictional Collaboration</td><td>Collected Asset Data / Agencies</td><td>BART would oversee this strategy in coordination with academic institutions.</td><td>Neutral</td></tr>
<tr><td>15</td><td>Funding availability</td><td>Agencies</td><td>No known available funding.</td><td>Unknown</td></tr>
<tr><td>16</td><td>Significant regulatory or legal issues</td><td>Agencies</td><td>No complications are assumed as this strategy only recommends conducting a study.</td><td>+</td></tr>
</table>

Drainage study (INFO)
Hayward SR-92

	Proposed Criteria	Input Source	Data	Scores
	Economy			
1	Marginal capital/program cost of adaptation strategy	AECOM/ CS / Agencies	Estimate = $500,000: This estimate includes staffing, equipment, training, conferences, etc. This metric needs best practices or examples of past grants to model ground/saltwater intrusion.	+
2	Annual operating and maintenance costs of adaptation strategy	AECOM / Agencies	This strategy is a study, and it is assumed that it's a one-time strategy even if results of the study are updated periodically.	0
3	Duration / life span of strategy	AECOM / CS / Agencies	This strategy is assumed to be a one-time study, which may have minor updates, but updates are not counted as on-going.	NA
4	Implementation coincidence with asset renewal cycle/CIP investment project or other point of intervention in existing design, planning processes	Collected Asset Data / Agencies	There is high potential to make this strategy fit it with ongoing assessments already being conducted by Caltrans	++
5	Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy. Quantitative evaluation will include changes in regional travel.	Travel model or PeMS 2014; Travel model output 2040 BART report	Travel data (SR92) AADT: 91000, AADTT: 5915 (For comparison, I-580 AADT 250000; SR-84 AADT 75000)	+
6	Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs.	Travel model or PeMS 2014; Travel model output 2040	Quantitative evaluation will include changes in regional travel delay.	TBD
	Social /Equity			
7	Social Co-benefits (homes protected)	County assessor or city parcel data	Indirect benefit based in improvements in project prioritization and infrastructure design based on this strategy.	+
8	Direct Social Co-benefits (jobs protected)		Indirect benefit based in improvements in project prioritization and infrastructure design based on this strategy.	+
9	Amenity Co-benefits (e.g., bike trail on new levee)	AECOM		NA
10	Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action (and potentially preserved due to event response) Not used for qualitative evaluation given data needs.	MTC Communities of Concern map	Quantitative evaluation will include changes in transit routes.	TBD
11	Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs.	MTC Communities of Concern and MTC Travel Demand Model	Quantitative evaluation will include changes in regional travel.	TBD
	Environmental			
12	Ecological value/function	AECOM / CDFG	Provides new hydrology data.	NA
13	GHG emissions - Change in automobile vehicle miles traveled (VMT): Not used for qualitative evaluation given data needs.	Travel model output 2040	Quantitative evaluation will include changes in regional travel and emissions.	TBD
	Governance			
14	Potential for Jurisdictional Collaboration	Collected Asset Data / Agencies	The involvement of agencies depends on the types of system modifications studied. Caltrans has jurisdiction over the kinds of strategies in the BMP Retrofit Pilot Program - Final Report and Appendix. However, for strategies involving storm sewers, other agencies will have to be included, such as the City of Hayward and ACFCWCD, etc. For scoring this strategy, it is assumed that Caltrans can implement most of the BMPs on their own.	Neutral
15	Funding availability	Agencies	No known available funding.	Unknown
16	Significant regulatory or legal issues	Agencies	No complications are assumed as this strategy only recommends conducting a study.	+

BART planning process update (GOV)

	Proposed Criteria	Input Source	Data	Scores
	Economy			
1	Marginal capital/program cost of adaptation strategy	AECOM/ CS / Agencies	Unknown. This estimate should include staffing cost, and for the purpose of scoring, the cost is assumed to be very low.	++
2	Annual operating and maintenance costs of adaptation strategy	AECOM / Agencies	This estimate is unknown for now, but a score of single positive is assigned based on pre-defined rationale.	+
3	Duration / life span of strategy	AECOM / CS / Agencies	This strategy is assumed to have a permanent life-span. The planning process may undergo minor updates, but the process will remain in place long-term.	++
4	Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes	Collected Asset Data / Agencies	There is high potential to make this strategy fit it with ongoing assessments already being conducted by Caltrans	++
5	Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy. Quantitative evaluation will include changes in regional travel.	Travel model or PeMS 2014; Travel model output 2040 BART report	This strategy should benefit the whole of the BART network, helping the prioritization of projects and lead to more resilient project design.	++
6	Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel delay.	Travel model or PeMS 2014; Travel model output 2040		TBD
	Social /Equity			
7	Social Co-benefits (homes protected)	County assessor or city parcel data		NA
8	Social Co-benefits (jobs protected)			NA
9	Amenity Co-benefits (e.g., bike trail on new levee)	AECOM		NA
10	Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action (and potentially preserved due to event response) Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in transit routes.	MTC Communities of Concern map		TBD
11	Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel.	MTC Communities of Concern and MTC Travel Demand Model		TBD
	Environmental			
12	Ecological value/function	AECOM		NA
13	GHG emissions - Change in automobile vehicle miles traveled (VMT). : Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel and emissions.	Travel model output 2040		TBD
	Governance			
14	Potential for Jurisdictional Collaboration	Collected Asset Data / Agencies	Only BART is involved and no complications are assumed.	-
15	Funding availability	Agencies	No known available funding.	Unknown
16	Significant regulatory or legal issues	Agencies	No known legal issues.	+

Caltrans Sea level Rise Guidance Enhancements (GOV)

	Proposed Criteria	Input Source	Notes	Scores
	Economy			
1	Marginal capital/program cost of adaptation strategy	AECOM/ CS / Agencies	Estimate = $50,000 - $500,000. This estimate includes staffing. An average of $50,000 - $500,000 is used to assign scoring.	+
2	Annual operating and maintenance costs of adaptation strategy	AECOM / Agencies	This strategy is a study, and it is assumed that it's a one-time strategy even if the results of the study are updated periodically.	Neutral
3	Duration / life span of strategy	AECOM / CS / Agencies	This strategy is assumed to be a one-time study, which may have minor updates, but these updates are not counted as on-going.	NA
4	Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes	Collected Asset Data / Agencies	There is high potential to make this strategy fit it with existing guidance developed by Caltrans on SLR.	++
5	Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy. Quantitative evaluation will include changes in regional travel.	Travel model or PeMS 2014; Travel model output 2040 BART report	This strategy should benefit the whole of the Caltrans network, helping the prioritization of projects and lead to more resilient project design.	++
6	Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel delay.	Travel model or PeMS 2014; Travel model output 2040		TBD
	Social /Equity			
7	Social Co-benefits (homes protected)	County assessor or city parcel data		NA
8	Direct Social Co-benefits (jobs protected)			NA
9	Amenity Co-benefits (e.g., bike trail on new levee)	AECOM		NA
10	Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action (and potentially preserved due to event response) Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in transit routes.	MTC CoC map		TBD
11	Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel.	MTC CoC and MTC Travel Demand Model		TBD
	Environmental			
12	Ecological value/function	AECOM		NA
13	GHG emissions - Change in automobile vehicle miles traveled (VMT). : Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel and emissions.	Travel model output 2040		TBD
	Governance			
14	Potential for Jurisdictional Collaboration	Collected Asset Data / Agencies	Only Caltrans is involved and no potential for collaboration are assumed.	-
15	Funding availability	Agencies	No known available funding.	Unknown
16	Significant regulatory or legal issues	Agencies	No known legal issues as this is just as study.	+

Coordinate with permitting agencies around SR-92 (GOV)
Hayward SR-92

	Proposed Criteria	Input Source	Notes	Score
	Economy			
1	Marginal capital/program cost of adaptation strategy	AECOM/ CS / Agencies	Unknown. This estimate should include staffing cost, and for the purpose of scoring, the cost is assumed to be very low.	++
2	Annual operating and maintenance costs of adaptation strategy	AECOM / Agencies	This estimate is unknown for now, but a score of single positive is assigned based on pre-defined rationale.	+
3	Duration / life span of strategy	AECOM / CS / Agencies	This strategy is assumed to have a permanent lifespan, which may have minor updates, but overall coordination process is assumed to be long-term.	++
4	Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes	Collected Asset Data / Agencies	This strategy would be a new requirement to improve required coordination processes in project development.	+
5	Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy. Quantitative evaluation will include changes in regional travel.	Travel model or PeMS 2014; Travel model output 2040 BART report	**SR-92** **AADT** 91,000 **AADTT** 5,915	+
6	Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel delay.	Travel model or PeMS 2014; Travel model output 2040		TBD
	Social /Equity			
7	Social Co-benefits (homes protected)	County assessor city parcel data	Indirect benefit based in improvements in project delivery based on this strategy.	+
8	Social Co-benefits (jobs protected)		Indirect benefit based in improvements in project delivery based on this strategy.	+
9	Amenity Co-benefits (e.g., bike trail on new levee)	AECOM		NA
10	Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action (and potentially preserved due to event response) Not used for qualitative evaluation given data needs.	MTC CoC map	Quantitative evaluation will include changes in transit routes.	TBD
11	Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs.	MTC CoC and MTC Travel Demand Model	Quantitative evaluation will include changes in regional travel.	TBD
	Environmental			
12	Ecological value/function	AECOM		NA
13	GHG emissions - Change in automobile vehicle miles traveled (VMT). : Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel and emissions.	Travel model output 2040		TBD
	Governance			
14	Potential for Jurisdictional Collaboration	Collected Asset Data / Agencies	High Potential for Jurisdictional Collaboration is assumed because of the number of agencies involved.	++
15	Funding availability	Agencies	No known available funding.	Unknown
16	Significant regulatory or legal issues	Agencies	Regulatory requirements are assumed as permitting agencies are involved.	-

Inter-Agency Coordination (Connected infrastructure) (GOV)
Bay Bridge Touchdown

<table>
<tr><th></th><th>Proposed Criteria</th><th>Input Source</th><th>Notes</th><th>Score</th></tr>
<tr><td></td><td>Economy</td><td></td><td></td><td></td></tr>
<tr><td>1</td><td>Marginal capital/program cost of adaptation strategy</td><td>AECOM/ CS / Agencies</td><td>Unknown. This estimate should include staffing cost, and for the purpose of scoring, the cost is assumed to be very low.</td><td>++</td></tr>
<tr><td>2</td><td>Annual operating and maintenance costs of adaptation strategy</td><td>AECOM / Agencies</td><td>This estimate is unknown for now, but a score of single positive is assigned based on pre-defined rationale.</td><td>+</td></tr>
<tr><td>3</td><td>Duration / life span of strategy</td><td>AECOM / CS / Agencies</td><td>This strategy is assumed to have a permanent lifespan, which may have minor updates, but overall coordination process assumed to be long-term.</td><td>++</td></tr>
<tr><td>4</td><td>Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes</td><td>Collected Asset Data / Agencies</td><td>This strategy would be a new requirement to improve required coordination processes in project development.</td><td>+</td></tr>
<tr><td>5</td><td>Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy. Quantitative evaluation will include changes in regional travel.</td><td>Travel model or PeMS 2014; Travel model output 2040
BART report</td><td><table><tr><th></th><th>I-80 Toll Plaza</th><th>I-80 Toll Plaza</th></tr><tr><td>AADT</td><td>95,054</td><td></td></tr><tr><td>BART/ AC Transit Transbay</td><td>197,681</td><td>9,994</td></tr></table></td><td>++</td></tr>
<tr><td>6</td><td>Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel delay.</td><td>Travel model or PeMS 2014; Travel model output 2040</td><td></td><td>TBD</td></tr>
<tr><td></td><td>Social /Equity</td><td></td><td></td><td></td></tr>
<tr><td>7</td><td>Social Co-benefits (homes protected)</td><td>County assessor or city parcel data</td><td>Indirect benefit based in improvements in project delivery based on this strategy.</td><td>+</td></tr>
<tr><td>8</td><td>Social Co-benefits (jobs protected)</td><td></td><td>Indirect benefit based in improvements in project delivery based on this strategy.</td><td>+</td></tr>
<tr><td>9</td><td>Amenity Co-benefits (e.g., bike trail on new levee)</td><td>AECOM</td><td></td><td>NA</td></tr>
<tr><td>10</td><td>Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action (and potentially preserved due to event response) Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in transit routes.</td><td>MTC Communities of Concern map</td><td></td><td>TBD</td></tr>
<tr><td>11</td><td>Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs.</td><td>MTC Communities of Concern and MTC Travel Demand Model</td><td>Quantitative evaluation will include changes in regional travel.</td><td>TBD</td></tr>
<tr><td></td><td>Environmental</td><td></td><td></td><td></td></tr>
<tr><td>12</td><td>Ecological value/function</td><td>AECOM</td><td></td><td>NA</td></tr>
<tr><td>13</td><td>GHG emissions - Change in automobile vehicle miles traveled (VMT): Not used for qualitative evaluation given data needs.</td><td>Travel model output 2040</td><td>Quantitative evaluation will include changes in regional travel and emissions.</td><td>TBD</td></tr>
<tr><td></td><td>Governance</td><td></td><td></td><td></td></tr>
<tr><td>14</td><td>Potential for Jurisdictional Collaboration</td><td>Collected Asset Data / Agencies</td><td>High Potential for Jurisdictional Collaboration is assumed because of the number of agencies involved.</td><td>++</td></tr>
<tr><td>15</td><td>Funding availability</td><td>Agencies</td><td>No known available funding.</td><td>Unknown</td></tr>
<tr><td>16</td><td>Significant regulatory or legal issues</td><td>Agencies</td><td>Coordination on its own is assumed to have no regulatory or legal complications</td><td>+</td></tr>
</table>

Physical Strategies – Qualitative evaluation

This section provides documentation of using the evaluation criteria on shortlisted Physical Strategies in a 'qualitative' way. Where quantitative data was readily available (e.g. from the data collection exercise) this data was noted to help inform the scoring. We have not however looked up MTC model tables, nor done any GIS analysis. For some of the costing we have made gross ball park assumptions (e.g. cost of levee either side of SR92 would be very high).

Bay Bridge Drainage System Modifications for the drainage area around I-80 segment between 40th St and Powell St and the drainage area around I-880 segment between 7th St and 40th St

Carry out a drainage study to identify current and future capacity issues in partnership with City of Oakland and Alameda County. Depending on the outcome of that study the following drainage system modifications may be appropriate.

Drainage System Modifications may include:

1. Realign drainage pipes to the minimum slope required to accommodate the design flow and raise the discharge points.
2. Reroute drainage pipes to a shorter route to a discharge point, allowing that new discharge point to be higher in elevation.
3. Add parallel drainage system as backup for the reduced flow rate in the existing system.
4. Install pumps.

Monitoring conditions in the meantime will be important to see how drainage functions particularly during high tide events.

Coliseum: Flow Restriction Reduction, I-880 Damon Slough Bridge

1. Widen creek under and downstream of bridge. This strategy may require partial channelization of creek with concrete walls or a gabion type of earth retaining structure.
2. Add culverts (pipes jacked under roadway) under Hwy 880 to provide for a supplemental flow path for the creek at times of high flows.

Hayward: Levee either side of the SR-92 causeway between Toll Plaza and Mainland

Build engineered levees parallel to SR92, with variable habitat on the backside of the levee. Roadway remains at existing grade and ultimately below flood level fully dependent on levee structures for protection. Would provide protection of critical public transportation infrastructure, but would visually cut off road from views of adjacent wetlands. Levees would need to consider ongoing restoration efforts (such as the South Bay Salt Pond Restoration Project), and be designed to integrate into restored/restoring habitat areas. Levee designs should be adaptable to provide increasing protection over time, if practical, to address changing conditions in the surrounding area.

Comparison of Scores across Strategies

	Proposed Criteria	Drainage System Modification (Bay Bridge)	Flow Restriction Reduction (Coliseum)	Levee on both sides of SR 92 (Hayward)
	Economy			
1	Marginal capital/program cost of adaptation strategy	+	Neutral	-
2	Annual operating and maintenance costs of adaptation strategy	-	-	-
3	Duration / life span of strategy	+	+	++
4	Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes	++	+	-
5	Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy. Quantitative evaluation will include changes in regional travel.	++	++	+
6	Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel delay.	TBD	TBD	TBD
	Social /Equity			
7	Social Co-benefits (homes protected)	Neutral	NA	Neutral
8	Social Co-benefits (jobs protected)	Neutral	-	Neutral
9	Amenity Co-benefits (e.g., bike trail on new levee)	Neutral	-	Neutral
10	Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action (and potentially preserved due to event response) Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in transit routes.	TBD	TBD	TBD
11	Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel.	TBD	TBD	TBD
	Environmental			
12	Ecological value/function	NA	-	Neutral
13	GHG emissions - Change in automobile vehicle miles traveled (VMT): Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel and emissions.	TBD	TBD	TBD
	Governance			
14	Potential for Jurisdictional Collaboration	Neutral	+	+
15	Funding availability	+	Unknown	Unknown
16	Significant regulatory or legal issues	+	-	--

Bay Bridge Drainage System Modifications for the drainage area around I-80 segment between 40th St and Powell St and the drainage area around I-880 segment between 7th St and 40th St

<table>
<tr><th></th><th>Proposed Criteria</th><th>Input Source</th><th colspan="3">[EXPECTED RANK]
Data</th><th>Scores</th></tr>
<tr><td></td><td>Economy</td><td></td><td colspan="3"></td><td></td></tr>
<tr><td>1</td><td>Marginal capital/program cost of adaptation strategy</td><td>AECOM/ CS / Agencies</td><td colspan="3">Estimate = $40,000 - $450,000. Estimates should account for density of drainage facilities along corridor. The Caltrans BMP Retrofit Pilot Program - Final Report and Appendix contains construction and maintenance costs of different types of storm-water management technologies. Caltrans has an existing budget for stormwater management systems. For scoring this strategy, an average of $40,000 and $450,000 was assumed.</td><td>+</td></tr>
<tr><td>2</td><td>Annual operating and maintenance costs of adaptation strategy</td><td>AECOM / Agencies</td><td colspan="3">This estimate in unknown for now. It depends on the type of drainage facilities that are currently in place, or may be in place in the future. Caltrans has an existing budget for stormwater management systems. The Caltrans BMP Retrofit Pilot Program - Final Report and Appendix contains construction and maintenance costs of different types of storm-water management technologies.</td><td>-</td></tr>
<tr><td>3</td><td>Duration / life span of strategy</td><td>AECOM / CS / Agencies</td><td colspan="3">Average life-span = 10 – 20 years. Life-span will depend on the type of drainage facilities that may be proposed, along with their design criteria. The Caltrans BMP Retrofit Pilot Program - Final Report and Appendix contains maintenance cycles for different types of storm-water management technologies. The maintenance cycle could be used as a proxy for the life-span of the proposed design modifications.</td><td>+</td></tr>
<tr><td>4</td><td>Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes</td><td>Collected Asset Data / Agencies</td><td colspan="3">Caltrans has an existing stormwater management program, and there is high potential for integration of this strategy with the existing program</td><td>++</td></tr>
<tr><td rowspan="4">5</td><td rowspan="4">Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy. Quantitative evaluation will include changes in regional travel.</td><td rowspan="4">Travel model or PeMS 2014; Travel model output 2040
BART report</td><td>Asset</td><td>Passenger Annual Average Daily Traffic (AADT)</td><td>Truck Annual Average Daily Traffic (AADT)</td><td></td></tr>
<tr><td>I-80 segment between 40th St and Powell St</td><td>241,000</td><td>12,933</td><td>++</td></tr>
<tr><td>I-880 segment between 7th St and 40th St</td><td>105,000</td><td>12,947</td><td>+</td></tr>
<tr><td colspan="3">AADT is defined as average daily traffic on a roadway link for all days of the week during a period of one year, expressed in vehicles per day (VPD).</td><td></td></tr>
<tr><td>6</td><td>Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel delay.</td><td>Travel model or PeMS 2014; Travel model output 2040</td><td colspan="3"></td><td>TBD</td></tr>
<tr><td></td><td>Social /Equity</td><td></td><td colspan="3"></td><td></td></tr>
<tr><td>7</td><td>Social Co-benefits (homes protected)</td><td>County assessor or city parcel data</td><td colspan="3">This strategy is very designed to be asset-specific.</td><td>0</td></tr>
<tr><td>8</td><td>Social Co-benefits (jobs protected)</td><td></td><td colspan="3">This strategy is very designed to be asset-specific</td><td>0</td></tr>
<tr><td>9</td><td>Amenity Co-benefits (e.g., bike trail on new levee)</td><td>AECOM</td><td colspan="3">This strategy is very designed to be asset-specific</td><td>0</td></tr>
<tr><td>10</td><td>Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action (and potentially preserved due to event response) Not used for qualitative evaluation given data needs.</td><td>MTC Communities of Concern map</td><td colspan="3">Quantitative evaluation will include changes in transit routes.</td><td>TBD</td></tr>
<tr><td>11</td><td>Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs.</td><td>MTC CoC and MTC Travel Demand Model</td><td colspan="3">Quantitative evaluation will include changes in regional travel.</td><td>TBD</td></tr>
<tr><td></td><td>Environmental</td><td></td><td colspan="3"></td><td></td></tr>
<tr><td>12</td><td>Ecological value/function</td><td>AECOM / CDFG</td><td colspan="3">This strategy is very designed to be asset-specific and is not intended to serve other purposes.</td><td>NA</td></tr>
</table>

	Proposed Criteria	Input Source	[EXPECTED RANK] Data	Scores
13	GHG emissions - Change in automobile vehicle miles traveled (VMT): Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel and emissions.	Travel model output 2040		TBD
	Governance			
14	Potential for Jurisdictional Collaboration	Collected Asset Data / Agencies	The involvement of agencies depends on the types of system modifications proposed. Caltrans has jurisdiction over the kinds of strategies in the BMP Retrofit Pilot Program - Final Report and Appendix. However, for strategies involving storm sewers, other agencies will have to be included, such as City of Oakland, Alameda County Flood Control District, etc. For scoring this strategy, it is assumed that Caltrans can implement most of the BMPs on their own.	0
15	Funding availability	Agencies	Caltrans has an existing budget for periodic stormwater system upgrades.	+
16	Significant regulatory or legal issues	Agencies	No additional regulatory or legal issues are assumed, as Caltrans already operates a variety of stormwater systems.	+

Coliseum: Flow Restriction Reduction, I-880 Damon Slough Bridge

	Proposed Criteria	Input Source	Data		Score
	Economy				
1	Marginal capital/program cost of adaptation strategy	AECOM/ CS / Agencies	- $400,000 for flow-diversion(for two jacked pipes under freeway): Cost of creek widening TBD Accounting for the cost of creek-widening, it is assumed that the total cost range will be between $500K and $1M		Neutral
2	Annual operating and maintenance costs of adaptation strategy	AECOM / Agencies	This estimate is unknown for now, but a score of single negative is assigned based on pre-defined rationale.		-
3	Duration / life span of strategy	AECOM / CS / Agencies	This estimate is unknown for now, but a score of single positive is assigned based on pre-defined rationale.		+
4	Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes	Collected Asset Data / Agencies	There is potential for integration with short-term capital planning projects in areas around the slough.		+
5	Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy. Quantitative evaluation will include changes in regional travel.	Travel model or PeMS 2014; Travel model output 2040	**Passenger Annual Average Daily Traffic (AADT)**	**Truck Annual Average Daily Traffic (AADT)**	
			200,000	15,280	++
6	Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs.	Travel model or PeMS 2014; Travel model output 2040	Quantitative evaluation will include changes in regional travel delay.		TBD
	Social /Equity				
7	Social Co-benefits (homes protected)	County assessor or city parcel data	This strategy is very designed to be asset-specific. There are no homes in the areas surrounding the asset which this strategy protects.		NA
8	Social Co-benefits (jobs protected)		Businesses directly adjacent to the slough may be impacted adversely by widening of the slough.		-
9	Amenity Co-benefits (e.g., bike trail on new levee)	AECOM	This strategy may have negative impacts on recreational services provided by the Coliseum complex		-
10	Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action (and potentially preserved due to event response) Not used for qualitative evaluation given data needs.	MTC Communities of Concern map	Quantitative evaluation will include changes in transit routes.		TBD
11	Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs.	MTC CoC and MTC TDM	Quantitative evaluation will include changes in regional travel.		TBD
	Environmental				
12	Ecological value/function	AECOM / CDFG	It is assumed that widening the creek just under and downstream of the bridge will have a slightly negative impact on ecological value of creek & surrounding habitat, and based on the strategy description, this negative impact is not going to be mitigated elsewhere.		-
13	GHG emissions - Change in automobile vehicle miles traveled (VMT): Not used for qualitative evaluation given data needs.	Travel model output 2040	Quantitative evaluation will include changes in regional travel and emissions.		TBD
	Governance				
14	Potential for Jurisdictional Collaboration	Collected Asset Data / Agencies	Some complexity is assumed as Caltrans will be required to coordinate with agencies overseeing the creek.		+
15	Funding availability	Agencies	No known funding available at this time.		Unknown
16	Significant regulatory or legal issues	Agencies	Some complexity is assumed based on stakeholders involved (Caltrans, Agencies overseeing creek, adjacent land-owners), and as a CEQA analysis is involved, but also keeping in mind that the scale of the project relatively small.		-

Hayward: Levee either side of the SR-92 causeway between Toll Plaza and Mainland

	Proposed Criteria	Input Source	[EXPECTED RANK] Data		Score
	Economy				
1	Marginal capital/program cost of adaptation strategy	AECOM/ CS / Agencies	Cost is unknown at this time. The cost would depend on width, height and design of levee. The cost is assumed to be between $1M - $10M		-
2	Annual operating and maintenance costs of adaptation strategy	AECOM / Agencies	Cost is unknown at this time. The cost would depend on width, height and design of levee. This estimate is unknown for now, but a score of single negative is assigned based on pre-defined rationale.		-
3	Duration / life span of strategy	AECOM / CS / Agencies	Levee life-spans are generally long-term.		++
4	Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes	Collected Asset Data / Agencies	This would be a new strategy, with no potential for integration.		-
5	Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy. Quantitative evaluation will include changes in regional travel.	Travel model or PeMS 2014; Travel model output 2040 BART report	**Passenger Annual Average Daily Traffic (AADT)**	**Truck Annual Average Daily Traffic (AADT)**	
			91,000	5,915	+
6	Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel delay.	Travel model or PeMS 2014; Travel model output 2040			TBD
	Social /Equity				
7	Social Co-benefits (homes protected)	County assessor or city parcel data	This is an asset specific strategy.		0
8	Social Co-benefits (jobs protected)		This is an asset specific strategy.		0
9	Amenity Co-benefits (e.g., bike trail on new levee)	AECOM	This is an asset specific strategy.		0
10	Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action (and potentially preserved due to event response) Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in transit routes.	MTC Communities of Concern map			TBD
11	Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs.	MTC Communities of Concern and MTC Travel Demand Model	Quantitative evaluation will include changes in regional travel.		TBD
	Environmental				
12	Ecological value/Function	AECOM / CDFG	It is assumed that this strategy will have a negative impact on adjacent wetlands, but based on the description, proper measures will be in place to mitigate those impacts.		Neutral
13	GHG emissions - Change in automobile vehicle miles traveled (VMT): Not used for qualitative evaluation given data needs.	Travel model output 2040	Quantitative evaluation will include changes in regional travel and emissions.		TBD
	Governance				
14	Potential for Jurisdictional Collaboration	Collected Asset Data / Agencies	Some complexity is assumed as Caltrans would have to collaborate with other agencies that have jurisdiction over the bay.		+
15	Funding availability	Agencies	No known funding identified at this point.		Unknown
16	Significant regulatory or legal issues	Agencies	The project scale is relatively large, and will likely trigger an in-depth CEQA analysis given the potential impacts of this strategy on adjacent wetland restoration projects.		--

Qualitative evaluation - Focus Area-wide Strategies

This section provides documentation of using the evaluation criteria on shortlisted Focus Area-wide Strategies in a 'qualitative' way. Where quantitative data was readily available (e.g. from the data collection exercise) this data was noted to help inform the scoring. We have not however looked up MTC model tables, nor done any GIS analysis. For some of the costing we have made gross ball park assumptions.

Bay Bridge Focus Area: Artificial Dunes:
Construct artificial dunes for the entire length of the low-lying section north of the Bay Bridge touchdown to retain the habitat value of that area, while providing protection to the HWY.

Bay Bridge Focus Area: Offshore Breakwater:
Construct an offshore breakwater to the north of the Bay Bridge touchdown. This would not mitigate sea level rise, but it would reduce storm surge and wave impacts, and it would provide protection to the HWY and the adjacent habitats (marsh, dunes, pocket sandy beaches), and it could provide protection to the Emeryville crescent marsh area. It would work in tandem with artificial dunes, needed to retain habitat in the longer term).

Bay Bridge Focus Area: Shoreline Protection (North of Bay Bridge):
Designed structure (such as an engineered berm with rock revetment, but maximizing the use of natural elements as much as possible to maintain the link with the valuable habitats in this area) alongside road corridor to north of bridge (I80). Include active management (such as periodic placement of sediment) and restoration of wetland to help the wetlands and habitats keep pace with SLR. Any shoreline structure constructed adjacent to I80 must take into account roadway drainage that would occur during rainfall events, and consider the feasibility of collecting (and potentially treating) the roadway drainage before disposal to the Bay.

Coliseum Focus Area: Damon Slough Tide Gate:
Block Damon Slough just west of I-880 and install a tide gate which will still allow the slough to drain during flood events and drop its sediment load behind the barrier, but deny sea level rise to the Coliseum area. The tide gate would have to be raised periodically because of both the sediment deposition and sea level rise, but that should be a small cost overall. This concept is similar in design to the Thames Flood Barrier (on a much smaller scale), and provides some transient storage. At more advanced levels of sea level rise where gravity flow is lost, provision for pumping stormwater to a point west of I-880 will need to be considered.

Coliseum Focus Area: Damon Slough Levee:
Construct levees adjacent to either edge of Damon Slough from east of I-880 to San Leandro St. to protect adjacent facilities and properties from future high tide levels. Mitigation for both habitat and recreation losses may need to be considered for this strategy. This does not include I-880 flood protection.

Coliseum Focus Area: Damon Slough Living Levee:
Use a combination of natural restoration and aesthetic levees/walls/berms along the length of Damon Slough. Also implement policy changes to prevent certain types of future land-use changes that would allow the construction of facilities vulnerable to future sea level rise. Because the footprint of walls, levees and berms would be relatively large, mitigation for loss of habitat and recreation may be required. This does not include I-880 flood proofing. This strategy will require land acquisition to be really be effective.

Hayward Focus Area: Marsh Management (Cooperative Landward Retreat):
A collective strategy to assess how the marshes and ponds North of SR 92 can be managed and maintained over time. Currently this complex is managed by numerous public agencies that provide a combination of flood control, wildlife habitat, recreation, and wastewater treatment. If this larger complex is managed more collectively, shifting uses could be considered over time between the smaller individual complexes. Over time, protective measures and habitat goals could be adapted to respond to rising sea level and work toward the best and highest use of the land at that time. Incremental retreat from the existing shoreline and restoration efforts could also encourage high marsh development and increase the longevity of the marsh habitat. This approach would entail establishing the primary line of defense for flood protection landward for much of the area (either by maintaining existing landward berms, or by constructing more substantial flood protection berms). Marshes and mudflats that are outboard of this line of defense would be allowed to transgress landward naturally with rising sea levels. This approach would allow tidal marshes to naturally reduce wave heights reaching the landward levee thereby reducing flood and erosion risks and potentially the height to which levees must be raised to provide adequate flood management. Over time, these outboard marshes may drown if they cannot keep pace with sea level rise, thereby reducing their wave and flood protection potential.

Hayward Focus Area: Maintain Existing Shoreline Alignment
This strategy would be to maintain the current shoreline alignment and associated habitat values for as long as is practical. Currently this complex is managed by numerous public agencies that provide a combination of flood control, wildlife habitat, recreation, and wastewater treatment. To maintain the existing shoreline (aka 'holding the line'), the bayside berm crest elevation would need to be raised to maintain existing levels of protection. This would require berm maintenance to keep pace with sea level rise. Although maintenance of the bayside berm could maintain the current mixture of uses in the near term, this measure may not work indefinitely as water level management within portions of the complex may become more difficult as sea levels rise. In the long-term, this outer berm could be surrounded on all sides by open water (as the marshes 'drown'), resulting in berms that will be more vulnerable to erosion and require increased long-term maintenance. In addition, as many of the berms are made of bay mud using local borrow material, there may be a maximum height to which the berms can be constructed (limited by geotechnical stability and availability of local borrow material). In the long-term, improving and maintaining the bayward berms may not be cost-effective, as rising sea levels (and subsequent marsh drowning) would eventually result in the levees becoming "peninsulas" that would be surrounded on all sides by open water, leaving them vulnerable to damage from wind-wave erosion and subject to increased long-term maintenance costs.

Comparison of Scores across Strategies

	Proposed Criteria	Bay Bridge Focus Area: Artificial Dunes	Bay Bridge Focus Area: Offshore Breakwater	Bay Bridge Focus Area: Shoreline Protection (North of Bay Bridge)	Coliseum Focus Area: Damon Slough Tide Gate	Coliseum Focus Area: Damon Slough Levee	Coliseum Focus Area: Damon Slough Living Levee	Hayward Focus Area: Marsh Management (Cooperative Landward Retreat)	Hayward Focus Area: Maintain Existing Shoreline Alignment
	Economy								
1	Marginal capital/program cost of adaptation strategy	-	-	-	--	--	--	-	-
2	Annual operating and maintenance costs of adaptation strategy	--	--	--	--	--	--	--	--
3	Duration / life span of strategy	++	++	++	++	++	++	++	++
4	Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes	-	-	-	-	-	-	+	+
5	Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy. Quantitative evaluation will include changes in regional travel.	++	++	++	++	++	++	NA	+
6	Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs.	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	Social /Equity								
7	Social Co-benefits (homes protected)	NA	NA	NA	NA	NA	NA	+	+
8	Social Co-benefits (jobs protected)	NA	NA	NA	+	+	+	+	+
9	Amenity Co-benefits (e.g., bike trail on new levee)	+	+	+	Neutral	Neutral	++	++	++
10	Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action) Not used for qualitative evaluation given data needs.	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
11	Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs.	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	Environmental								
12	Ecological value/function	+	+	+	+	Neutral	Neutral	++	+
13	GHG emissions - Change in automobile vehicle miles traveled (VMT): Not used for qualitative evaluation given data needs.	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	Governance								
14	Potential for Jurisdictional Collaboration	++	++	++	++	++	++	++	++
15	Funding availability	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
16	Significant regulatory or legal issues	--	--	--	-	-	-	--	--

Bay Bridge Focus Area: Artificial Dunes:

	Proposed Criteria	Input Source	Notes	Score
	Economy			
1	Marginal capital/program cost of adaptation strategy	AECOM/ CS / Agencies	The costs for this strategy would be refined during conceptual design, but the cost would likely exceed $1,000,000 for this length of shoreline (for engineering design and implementation). The ultimate cost will also depend on the level of protection desired (2050 + 100-year storm surge, 2100 + 100-year storm surge).	-
2	Annual operating and maintenance costs of adaptation strategy	AECOM / Agencies	This strategy may require maintenance and periodic inspection, particularly during the first few years after construction to assess subsidence and vegetation establishment, and after significant storm events to assess erosion and/or repair needs. The score for this criterion is assigned based on pre-defined rationale.	--
3	Duration / life span of strategy	AECOM / CS / Agencies	Life-span: 30 + years. It is assumed that the structure is designed and constructed to provide protection through 2050 conditions. The design should consider options that can be implemented at a later date to increase the level of protection if required (i.e., to meet 2100 conditions, or if sea levels rise faster than anticipated, or storm intensities increase). The lifespan of this structure would increase if implemented in tandem with the offshore breakwater. The offshore breakwater could be part of the longer-term adaptation strategy for this area. The score for this criterion is assigned based on pre-defined rationale.	++
4	Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes	Collected Asset Data / Agencies	This would be a new structure and there is no potential for integration.	-
5	Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy.	Travel model or PeMS 2014; Travel model output 2040	A high score is assigned based on the AADT magnitude for I80 and I880.	++
6	Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs.	Travel model or PeMS 2014; Travel model output 2040	Quantitative evaluation will include changes in regional travel delay.	TBD
	Social /Equity			
7	Social Co-benefits (homes protected)	County assessor or city parcel data	There are not homes in direct vicinity.	NA
8	Social Co-benefits (businesses protected)		There are no businesses in direct vicinity.	NA
9	Amenity Co-benefits (e.g., bike trail on new levee)	AECOM	This strategy protects recreational assets such as radio beach and some marshes.	+
10	Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action (and potentially preserved due to event response) Not used for qualitative evaluation given data needs.	MTC Communities of Concern map	Quantitative evaluation will include changes in transit routes.	TBD
11	Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs.	MTC CoC and MTC Travel Demand Model	Quantitative evaluation will include changes in regional travel.	TBD
	Environmental			
12	Ecological value/function	AECOM		+
13	GHG emissions - Change in automobile vehicle miles traveled (VMT): Not used for qualitative evaluation given data needs.	Travel model output 2040	Quantitative evaluation will include changes in regional travel and emissions.	TBD
	Governance			
14	Potential for Jurisdictional Collaboration	Collected Asset Data/Agencies	Caltrans as lead agency; BCDC; EBRPD	++
15	Funding availability	Agencies	None available	Unknown
16	Significant regulatory or legal issues	Agencies	Permitting would be required, including CEQA.	--

Bay Bridge Focus Area: Offshore Breakwater:

	Proposed Criteria	Input Source	Notes	Score
	Economy			
1	Marginal capital/program cost of adaptation strategy	AECOM/ CS / Agencies	TBD – An evaluation on the length, height (referenced to bathymetric depth), geotechnical conditions, and optimal placement would need to be completed to refine the cost estimate. The cost would exceed $1,000,000 (and could exceed $10,000,000 pending design). For purpose of assigning a score, a value between $1M and $10M is assumed.	-
2	Annual operating and maintenance costs of adaptation strategy	AECOM / Agencies	The score for this criterion is assigned based on pre-defined rationale.	--
3	Duration / life span of strategy	AECOM / CS / Agencies	50 years – This strategy would require periodic inspection, particularly during the first few years after construction to assess settlement and subsidence, and after significant storm events to assess erosion and/or repair needs. The score for this criterion is assigned based on pre-defined rationale.	++
4	Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes	Collected Asset Data / Agencies	This would be a new structure and there is no potential for integration.	-
5	Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy. Quantitative evaluation will include changes in regional travel.	Travel model or PeMS 2014; Travel model output 2040 BART report	A high score is assigned based on the AADT magnitude for I80 and I880.	++
6	Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel delay.	Travel model or PeMS 2014; Travel model output 2040		TBD
	Social /Equity			
7	Social Co-benefits (homes protected)	County assessor/city parcel data	There are not homes in direct vicinity.	NA
8	Social Co-benefits (businesses protected)		There are no businesses in direct vicinity.	NA
9	Amenity Co-benefits (e.g., bike trail on new levee)	AECOM	This strategy protects recreational assets such as radio beach and some marshes.	+
10	Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action (potentially preserved due to event response) Not used for qualitative evaluation given data needs.	MTC Communities of Concern map	Quantitative evaluation will include changes in transit routes.	TBD
11	Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs.	MTC CoC and MTC Travel Demand Model	Quantitative evaluation will include changes in regional travel.	TBD
	Environmental			
12	Ecological value/function	AECOM	This strategy could have ecological impacts on Bay habitats, and could also provide protection for some habitats. This would need to be assessed and optimized during design and impact assessment.	+
13	GHG emissions - Change in automobile vehicle miles traveled (VMT): Not used for qualitative evaluation given data needs.	Travel model output 2040	Quantitative evaluation will include changes in regional travel and emissions.	TBD
	Governance			
14	Potential for Jurisdictional Collaboration	Collected Asset Data / Agencies	Caltrans as lead agency, BCDC, EBRPD, USACE, Coastal Conservancy	++
15	Funding availability	Agencies	No	Unknown
16	Significant regulatory or legal issues	Agencies	Permitting would be required, CEQA required. This strategy would be the most difficult of the north Bay Bridge strategies with respect to permitting.	--

Bay Bridge Focus Area: Shoreline Protection (North of Bay Bridge):

	Proposed Criteria	Input Source	Notes	Score
	Economy			
1	Marginal capital/program cost of adaptation strategy	AECOM/ CS / Agencies	TBD – Cost would likely exceed $800,000 for this length of shoreline. The ultimate cost will also depend on the level of protection desired (2050 + 100-year storm surge, 2100 + 100-year storm surge).	-
2	Annual operating and maintenance costs of adaptation strategy	AECOM / Agencies	TBD –May require periodic inspection after significant storm events to assess erosion and/or repair needs. Would require active management of wetlands through sediment placement, including bi-annual monitoring of wetlands to determine need for sediment placement. Cost could exceed $100,000 every 5-10 years. Need for sediment placement to maintain wetlands could decrease if coupled with offshore breakwater strategy	--
3	Duration / life span of strategy	AECOM / CS / Agencies	30 + years. Assumption that the structure is designed and constructed to provide protection through 2050 conditions. The design should consider options that can be implemented at a later date to increase the level of protection if required (i.e., to meet 2100 conditions, or if sea levels rise faster than anticipated, or storm intensities increase). The lifespan of this structure would increase if implemented in tandem with the offshore breakwater. The offshore breakwater could be part of longer-term adaptation strategy for this area.	++
4	Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes	Collected Asset Data / Agencies		-
5	Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy.	Travel model or PeMS 2014; Travel model output 2040 BART report	A high score is assigned based on the AADT magnitude. Quantitative evaluation will include changes in regional travel.	++
6	Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs.	Travel model or PeMS 2014; Travel model output 2040	Quantitative evaluation will include changes in regional travel delay.	TBD
	Social /Equity			
7	Social Co-benefits (homes protected)	County assessor or city parcel data	There are not homes in direct vicinity.	NA
8	Social Co-benefits (businesses protected)		There are no businesses in direct vicinity.	NA
9	Amenity Co-benefits (e.g., bike trail on new levee)	AECOM	Yes, to a small extent. Could help maintain the habitat/park-like features in this area, which is currently publicly accessible	+
10	Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action (and potentially preserved due to event response) Not used for qualitative evaluation given data needs.	MTC Communities of Concern map	Quantitative evaluation will include changes in transit routes.	TBD
11	Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs.	MTC CoC and MTC Travel Demand Model	Quantitative evaluation will include changes in regional travel.	TBD
	Environmental			
12	Ecological value/function	AECOM / CDFG	Some. Emphasis for this strategy would be on protection, with natural elements incorporated as is practical / feasible.	+
13	GHG emissions - Change in automobile vehicle miles traveled (VMT): Not used for qualitative evaluation given data needs.	Travel model output 2040	Quantitative evaluation will include changes in regional travel and emissions.	TBD
	Governance			
14	Potential for Jurisdictional Collaboration	Collected Data / Agencies	Caltrans as lead agency, BCDC, EBRPD	++
15	Funding availability	Agencies	No	Unknown
16	Significant regulatory or legal issues	Agencies	Permitting would be required, CEQA required	--

Coliseum Focus Area: Damon Slough Tide Gate:

	Proposed Criteria	Input Source	Notes	Score
	Economy			
1	Marginal capital/program cost of adaptation strategy	AECOM/ CS / Agencies	The costs for this strategy would be refined during conceptual design, but the cost would likely be in the range of $10,000,000 to $20,000,000.	--
2	Annual operating and maintenance costs of adaptation strategy	AECOM / Agencies	O&M is required, including periodic monitoring of sediment deposition behind the tide gate. O&M could exceed $100,000 annually depending on sediment deposition rates. Upstream projects that act to reduce the sediment load in the tributaries would reduce the O&M costs for the tide gate structures.	--
3	Duration / life span of strategy	AECOM / CS / Agencies	20 years. After 20 years, the tide gage would need to be raised. The tide gate may need to be raised at an earlier interval depending on sediment deposition. Upstream projects that act to reduce the sediment load in the tributaries would extend the lifespan on this structure and reduce the need for periodic raising of the structure.	++
4	Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes	Collected Asset Data / Agencies		-
5	Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy. Quantitative evaluation will include changes in regional travel.	Travel model or PeMS 2014; Travel model output 2040 BART report	A high score is assigned based on the AADT magnitude	++
6	Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel delay.	Travel model or PeMS 2014; Travel model output 2040		TBD
	Social /Equity			
7	Social Co-benefits (homes protected)	County assessor or city parcel data	There are not homes in direct vicinity.	NA
8	Social Co-benefits (businesses protected)			+
9	Amenity Co-benefits (e.g., bike trail on new levee)	AECOM		Neutral
10	Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action (and potentially preserved due to event response) Not used for qualitative evaluation given data needs.	MTC Communities of Concern map	Quantitative evaluation will include changes in transit routes.	TBD
11	Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs.	MTC Communities of Concern and MTC Travel Demand Model	Quantitative evaluation will include changes in regional travel.	TBD
	Environmental			
12	Ecological value/function	AECOM / CDFG		+
13	GHG emissions - Change in automobile vehicle miles traveled (VMT): Not used for qualitative evaluation given data needs.	Travel model output 2040	Quantitative evaluation will include changes in regional travel and emissions.	TBD
	Governance			
14	Potential for Jurisdictional Collaboration	Collected Asset Data / Agencies	Oakland-Alameda County Coliseum Authority, Oakland Coliseum Joint Venture, Caltrans	++
15	Funding availability	Agencies	Unknown	unknown
16	Significant regulatory or legal issues	Agencies	Permitting would be required	-

Coliseum Focus Area: Damon Slough Levee:

	Proposed Criteria	Input Source	Notes	Score
	Economy			
1	Marginal capital/program cost of adaptation strategy	AECOM/ CS / Agencies	TBD -- The costs for this strategy would be refined during conceptual design, but the cost would likely be in the range of $10,000,000 to $20,000,000.	--
2	Annual operating and maintenance costs of adaptation strategy	AECOM / Agencies	Bi-annual inspections and inspections after large storm events.	--
3	Duration / life span of strategy	AECOM / CS / Agencies	30+ years. After 30 years, the levee heights may need to be raised to accommodate accelerated sea level rise or increasing storm intensities.	++
4	Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes	Collected Asset Data / Agencies	N/A	-
5	Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy. Quantitative evaluation will include changes in regional travel.	Travel model or PeMS 2014; Travel model output 2040 BART report	A high score is assigned based on the AADT magnitude	++
6	Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel delay.	Travel model or PeMS 2014; Travel model output 2040		TBD
	Social /Equity			
7	Social Co-benefits (homes protected)	County assessor or city parcel data	There are not homes in direct vicinity.	NA
8	Social Co-benefits (businesses protected)			+
9	Amenity Co-benefits (e.g., bike trail on new levee)	AECOM		Neutral
10	Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action (and potentially preserved due to event response) Not used for qualitative evaluation given data needs.	MTC Communities of Concern map	Quantitative evaluation will include changes in transit routes.	TBD
11	Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs.	MTC Communities of Concern and MTC Travel Demand Model	Quantitative evaluation will include changes in regional travel.	TBD
	Environmental			
12	Ecological value/function	AECOM / CDFG	This strategy could decrease the ecological / habitat values in Damon Slough and require habitat mitigation. However, based on the strategy description, it is assumed that damage to ecological habitat will be mitigated elsewhere. Therefore, a neutral score is assigned.	Neutral
13	GHG emissions - Change in automobile vehicle miles traveled (VMT): Not used for qualitative evaluation given data needs.	Travel model output 2040	Quantitative evaluation will include changes in regional travel and emissions.	TBD
	Governance			
14	Potential for Jurisdictional Collaboration	Collected Asset Data / Agencies	Oakland-Alameda County Coliseum Authority, Oakland Coliseum Joint Venture, Caltrans	++
15	Funding availability	Agencies	None available	Unknown
16	Significant regulatory or legal issues	Agencies	Permitting would be required	-

Coliseum Focus Area: Damon Slough Living Levee:

	Proposed Criteria	Input Source	Notes	Score
	Economy			
1	Marginal capital/program cost of adaptation strategy	AECOM/ CS / Agencies	TBD -- The costs for this strategy would be refined during conceptual design, but the cost would likely be in the range of $10,000,000 to $20,000,000.	--
2	Annual operating and maintenance costs of adaptation strategy	AECOM / Agencies	TBD -- This strategy may require maintenance and periodic inspection, particularly during the first few years after construction to assess subsidence and vegetation establishment, and after significant storm events to assess erosion and/or repair needs.	--
3	Duration / life span of strategy	AECOM / CS / Agencies	30 + years. Assumption that the structure is designed and constructed to provide protection through 2050 conditions. The design should consider options that can be implemented at a later date to increase the level of protection if required (i.e., to meet 2100 conditions, or if sea levels rise faster than anticipated, or storm intensities increase).	++
4	Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes	Collected Asset Data / Agencies	N/A	-
5	Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy.	Travel model or PeMS 2014; Travel model output 2040	A high score is assigned based on the AADT magnitude. Quantitative evaluation will include changes in regional travel.	++
6	Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs. Quantitative evaluation will include changes in regional travel delay.	Travel model or PeMS 2014; Travel model output 2040		TBD
	Social /Equity			
7	Social Co-benefits (homes protected)	County assessor or city parcel data	There are not homes in direct vicinity.	NA
8	Social Co-benefits (businesses protected)			+
9	Amenity Co-benefits (e.g., bike trail on new levee)	AECOM	This strategy can/should be integrated with public access elements. In addition to protecting the coliseum area, it also provides potential bike trails.	++
10	Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action (and potentially preserved due to event response) Not used for qualitative evaluation given data needs.	MTC Communities of Concern map	Quantitative evaluation will include changes in transit routes.	TBD
11	Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs.	MTC CoC & MTC Travel Demand Model	Quantitative evaluation will include changes in regional travel.	TBD
	Environmental			
12	Ecological value/function	AECOM / CDFG	This strategy could decrease the ecological / habitat values in Damon Slough and require habitat mitigation. However, based on the strategy description, it is assumed that damage to ecological habitat will be mitigated elsewhere. Therefore, a neutral score is assigned.	Neutral
13	GHG emissions - Change in automobile vehicle miles traveled (VMT): Not used for qualitative evaluation given data needs.	Travel model output 2040	Quantitative evaluation will include changes in regional travel and emissions.	TBD
	Governance			
14	Potential for Jurisdictional Collaboration	Collected Data / Agencies	Oakland-Alameda County Coliseum Authority, Oakland Coliseum Joint Venture, Caltrans	++
15	Funding availability	Agencies	None available	Unknown
16	Significant regulatory or legal issues	Agencies	Permitting would be required	-

Hayward Focus Area: Marsh Management (Cooperative Landward Retreat):

	Proposed Criteria	Input Source	Notes	Scores
	Economy			
1	Marginal capital/program cost of adaptation strategy	AECOM/ CS / Agencies	TBD – Cost will depend on the primary line of defense selected, incl protection of critical infrastructure. Improvements to these levees/berms will likely cost in excess of $5M. The flood protection standard for these features will control cost, and it is assumed that these features do *not* need to meet USACE or FEMA requirements for 100-year flood protection structures. As part of the analysis / design process, the threshold height for berm construction should be assessed.	-
2	Annual operating and maintenance costs of adaptation strategy	AECOM / Agencies	TBD – Ongoing O&M of the levees/berms will consist of regular inspections and inspections after storm events. Repairs and maintenance on an as-needed basis. Estimated annual O&M budget of $250,000 annually, to be refined during conceptual and preliminary design.	--
3	Duration / life span of strategy	AECOM / CS / Agencies	20 years. The levee/berm upgrades and maintenance should be designed to support conditions through 2050. An adaptation and/or retreat strategy may be needed after 2050.	++
4	Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes	Collected Asset Data / Agencies	N/A	+
5	Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy.	Travel model or PeMS 2014; Travel model output 2040 BART report	Quantitative evaluation will include changes in regional travel.	NA
6	Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs.	Travel model or PeMS 2014; Travel model output 2040	Quantitative evaluation will include changes in regional travel delay.	TBD
	Social /Equity			
7	Social Co-benefits (homes protected)	County assessor or city parcel data	This strategy will provide protection to the landward areas, including homes. This protection will diminish over time as this area moves toward retreat. A more significant solution will be required in this area in the future (likely after 2050) to provide landward flood protection.	+
8	Social Co-benefits (businesses protected)			+
9	Amenity Co-benefits (e.g., bike trail on new levee)	AECOM	Public access will likely be a mixed use that can be prioritized over time.	++
10	Change in # of transit routes in or within ½ mile of communities of concern disrupted in no action (and potentially preserved due to event response) Not used for qualitative evaluation given data needs.	MTC Communities of Concern map	Quantitative evaluation will include changes in transit routes.	TBD
11	Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs.	MTC Communities of Concern and MTC Travel Demand Model	Quantitative evaluation will include changes in regional travel.	TBD
	Environmental			
12	Ecological value/function	AECOM / CDFG	Yes – retreat efforts will be coordinated to maximize habitat values	++
13	GHG emissions - Change in automobile vehicle miles traveled (VMT): Not used for qualitative evaluation given data needs.	Travel model output 2040	Quantitative evaluation will include changes in regional travel and emissions.	TBD
	Governance			
14	Potential for Jurisdictional Collaboration	Collected Asset Data / Agencies	Hayward Area Recreation & Park District,, East Bay Regional Parks District, HPSA, BCDC	++
15	Funding availability	Agencies	None available	Unknown
16	Significant regulatory or legal issues	Agencies	Permitting will be required, CEQA likely required.	--

Hayward Focus Area: Maintain Existing Shoreline Alignment

	Proposed Criteria	Input Source	Notes	Scores
	Economy			
1	Marginal capital/program cost of adaptation strategy	AECOM/ CS / Agencies	TBD – Cost will depend on the primary line of defense selected, including protection of critical infrastructure. Improvements to these levees/berms will likely cost in excess of $5,000,000. The flood protection standard for these features will control cost, and it is assumed that these features do *not* need to meet USACE or FEMA requirements for 100-year flood protection structures. As part of the analysis and design process, the threshold height for berm construction should be assessed.	-
2	Annual operating and maintenance costs of adaptation strategy	AECOM / Agencies	TBD – Ongoing O&M of the levees/berms will consist of regular inspections and inspections after storm events. Repairs and maintenance on an as-needed basis. Estimated annual O&M budget of $250,000 annually, to be refined during conceptual and preliminary design.	--
3	Duration / life span of strategy	AECOM / CS / Agencies	20 years. The levee/berm upgrades and maintenance should be designed to support conditions through 2050. An adaptation and/or retreat strategy may be needed after 2050.	++
4	Implementation coincidence with asset renewal cycle/CIP investment project or other relevant point of intervention in existing design, planning processes	Collected Asset Data / Agencies	N/A	+
5	Mobility impact - Operating: Reflects historical traffic data (AADT) for qualitative evaluation, reflecting use and potential avoided disruption due to strategy.	Travel model or PeMS 2014; Travel model output 2040	Quantitative evaluation will include changes in regional travel.	+
6	Mobility impact (roadways) - Roadway Congestion: Not used for qualitative evaluation given data needs.	Travel model or PeMS 2014; Travel model output 2040	Quantitative evaluation will include changes in regional travel delay.	TBD
	Social /Equity			
7	Social Co-benefits (homes protected)	County assessor or city parcel data	This strategy will provide protection to the landward areas, including homes. This protection will diminish over time as this area moves toward retreat. A more significant solution will be required in this area in the future (likely after 2050) to provide landward flood protection.	+
8	Social Co-benefits (businesses protected)			+
9	Amenity Co-benefits (e.g., bike trail on new levee)	AECOM	Although public access can be integrated, it is not the focus of this strategy.	+
10	Change in # of transit routes in or within ½ mile of CoC disrupted in no action (and potentially preserved due to event response) Not used for qualitative evaluation given data needs.	MTC Communities of Concern map	Quantitative evaluation will include changes in transit routes.	TBD
11	Change in vehicle hours of delay for trips in lowest income category (compared to all other income categories): Not used for qualitative evaluation given data needs.	MTC Communities of Concern and MTC Travel Demand Model	Quantitative evaluation will include changes in regional travel.	TBD
	Environmental			
12	Ecological function/value	AECOM / CDFG	Yes – but only intrinsically. As levees meet their threshold heights, retreat may occur and areas will be allowed to revert to wetlands and mudflat (natural habitat), but a plan will not be put in place to actively restore or manage these areas.	+
13	GHG emissions - Change in automobile vehicle miles traveled (VMT): Not used for qualitative evaluation given data needs.	Travel model output 2040	. Quantitative evaluation will include changes in regional travel and emissions.	NA
	Governance			
14	Potential for Jurisdictional Collaboration	Collected Asset Data / Agencies	Hayward Area Recreation & Park District, East Bay Regional Parks District, HPSA, BCDC	++
15	Funding availability	Agencies	None available	-
16	Significant regulatory or legal issues	Agencies	Permitting will be required; CEQA may be required	--