CLIMATE CHANGE AND EXTREME WEATHER ADAPTATION OPTIONS

FOR TRANSPORTATION ASSETS IN THE BAY AREA PILOT PROJECT

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13. ABSTRACT (Maximum 200 words)

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 in Alameda County. This study builds on the Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project which was completed in 2011 and identified representative critical transportation assets vulnerable to sea level rise. Both projects were funded by the Federal Highway Administration. 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.

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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
NAVD88	North American Vertical Datum of 1988
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

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.

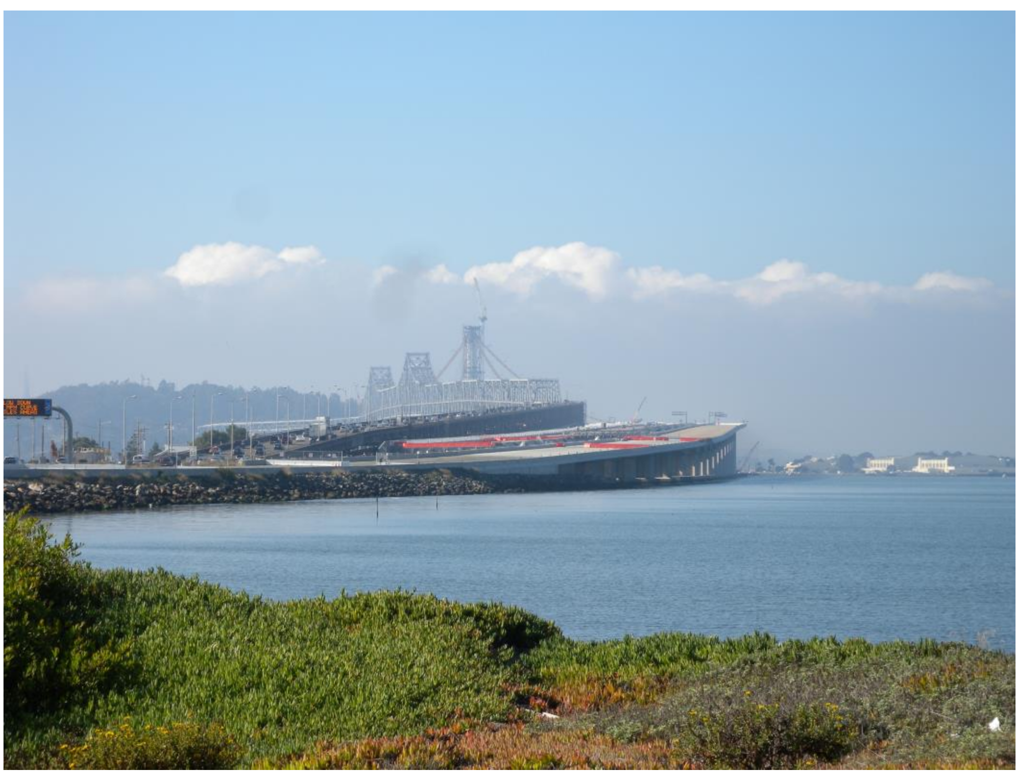
- Five refined representative adaptation options with specific and detailed actions including identification of timing, responsible parties, and methods for implementation
- A suite of criteria used first to select representative adaptation strategies from the long list and then second to evaluate the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

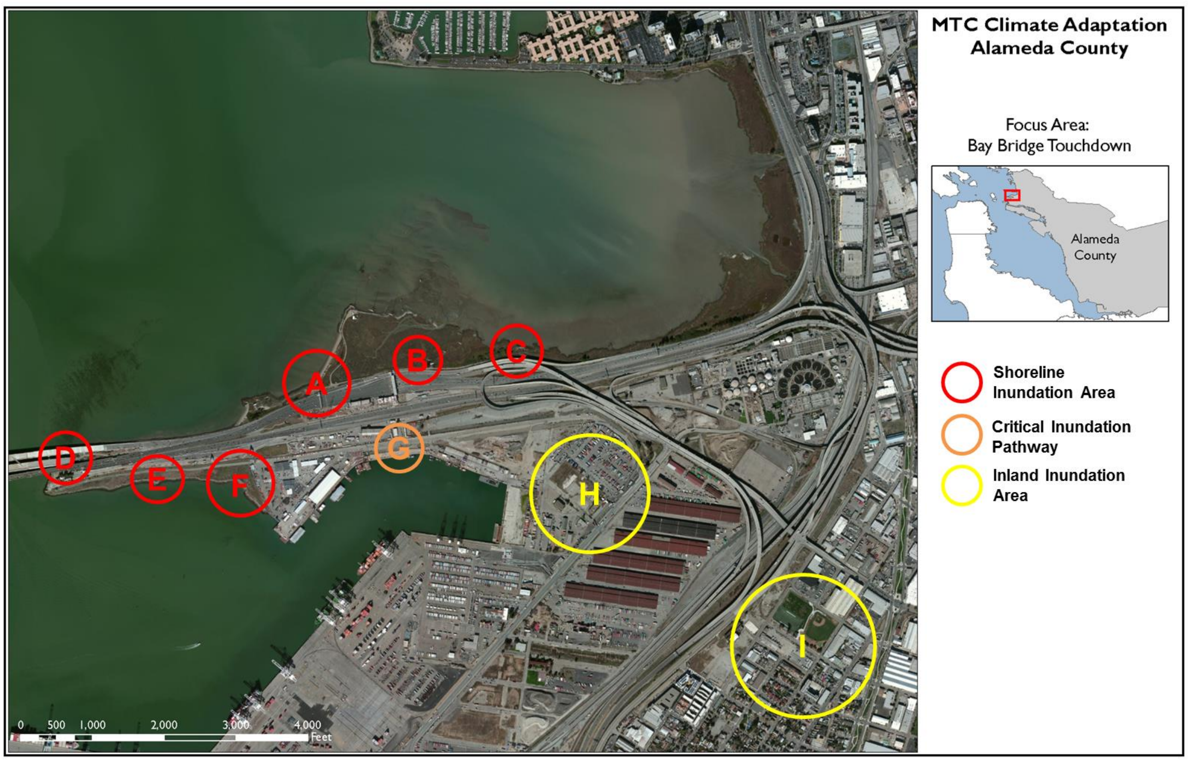
For the Coliseum focus area, an additional riverine flooding analysis was undertaken, as this region is expected to experience a combination of SLR and riverine flooding in the future. Based on the inundation maps that were produced as a result of the SLR and riverine flooding exposure analysis, the 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 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, 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

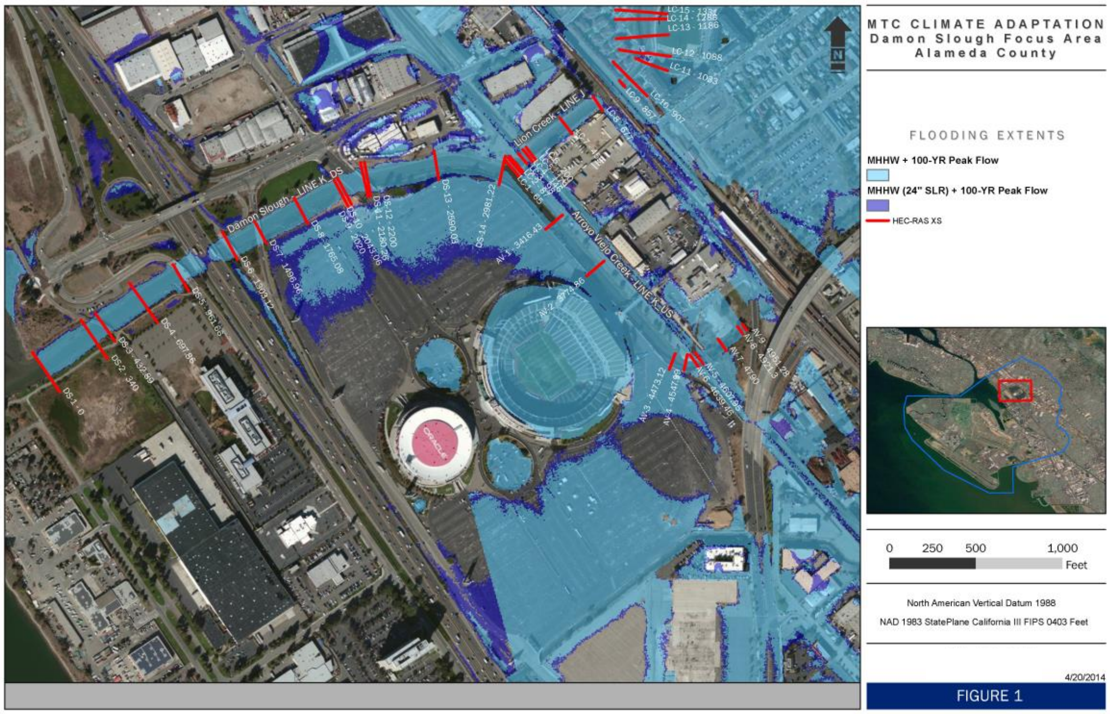
Within the Coliseum Focus Area, several important assets were identified as vulnerable to riverine flooding in addition to inundation by sea level rise and coastal storm surge. These assets are located in the vicinity of Damon Slough and the surrounding tributaries (Arroyo Viejo Creek and Lion Creek), 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 IV. 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 **Error! Not a valid bookmark self-reference.** (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 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 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).

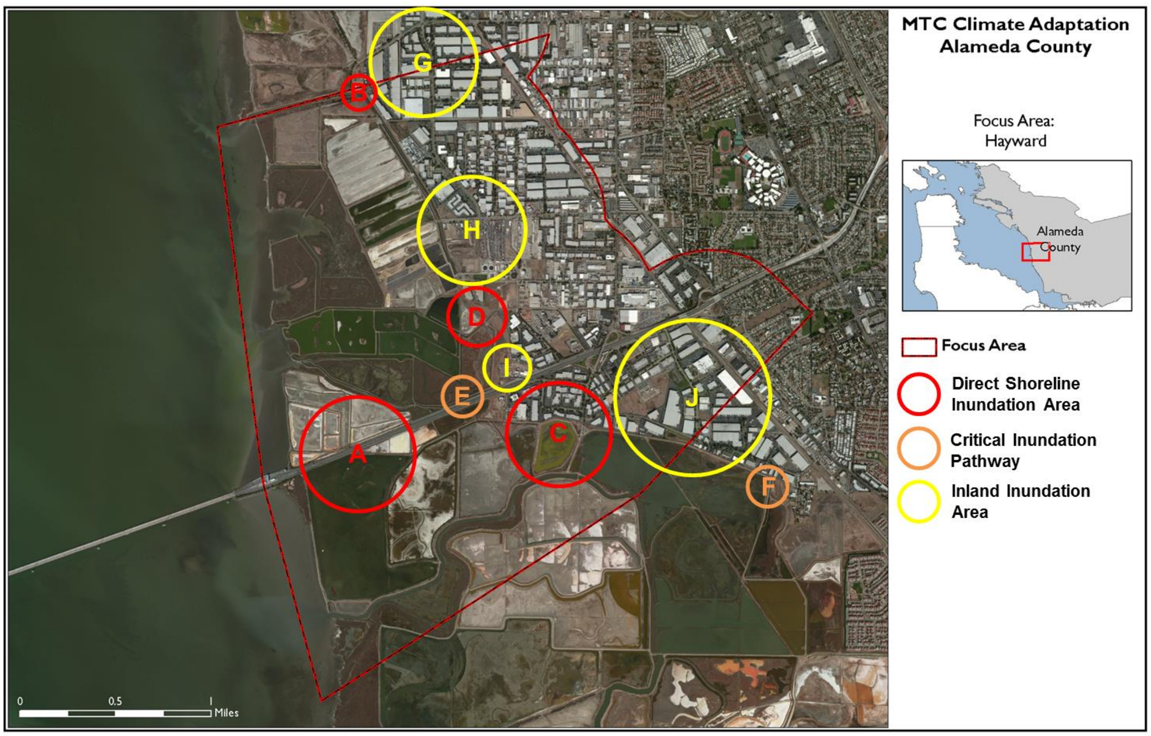
There are eight distinct marsh areas or ponds within the Hayward focus area, and these areas are separated by a network of internal and bayfront berms. The majority of this system is part of the Hayward Regional Shoreline, with the exception of Eden Landing Ecological Reserve, which is part of the Eden 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 and Figure).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.

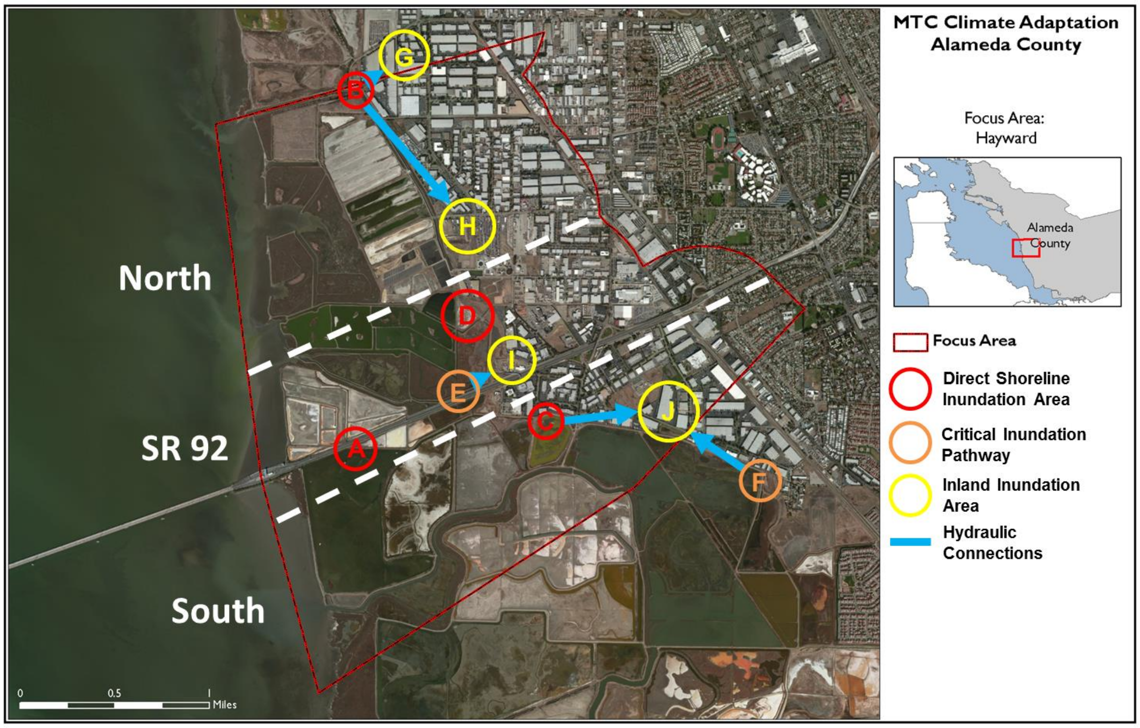
This extensive area along Arden Road and Trust Way is exposed due to overtopping of non-engineered berms at Area C and overtopping of the critical inundation pathway at Area F. Full details of the vulnerability of this focus area can be found in Section 3.4.

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?

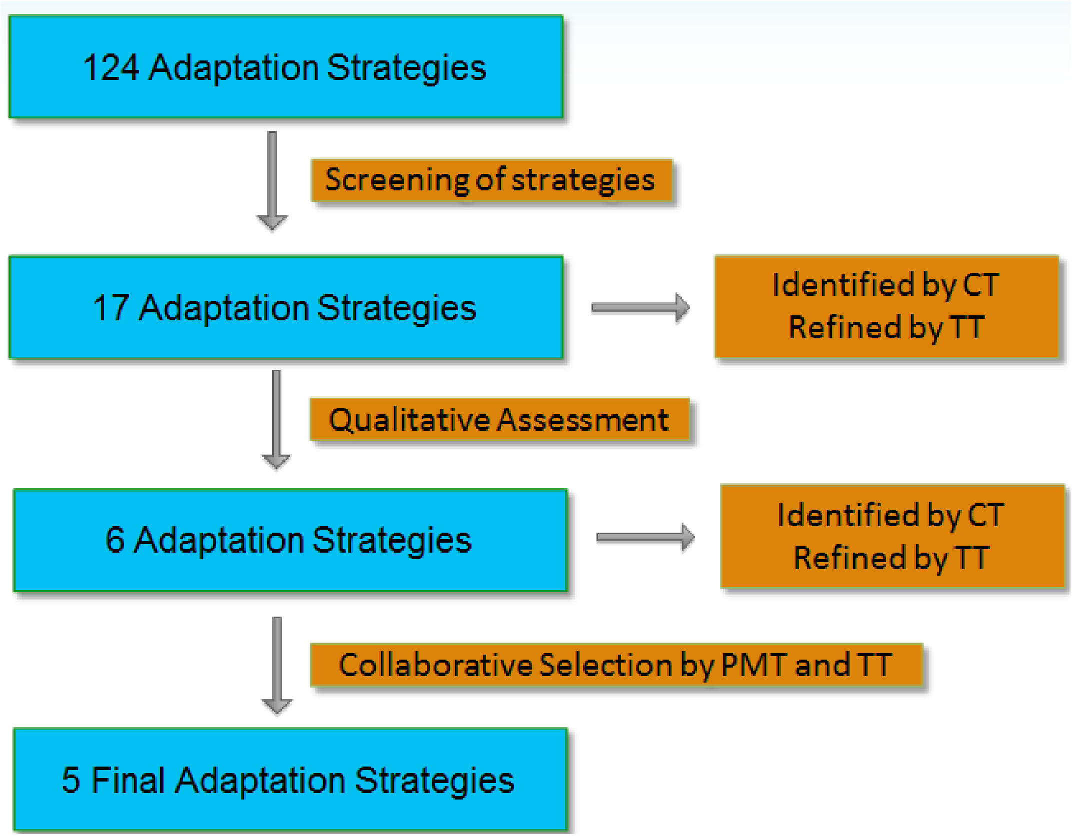
4. Can the strategy be used by more than one agency?
5. Does it make sense to start working on this strategy in the next 5 years?
6. Does the strategy address multiple transportation modes?
7. Does the strategy accomplish or contribute to other critical operational objectives (congestion management)?
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 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 and Figure 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).

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). 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 State 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. 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

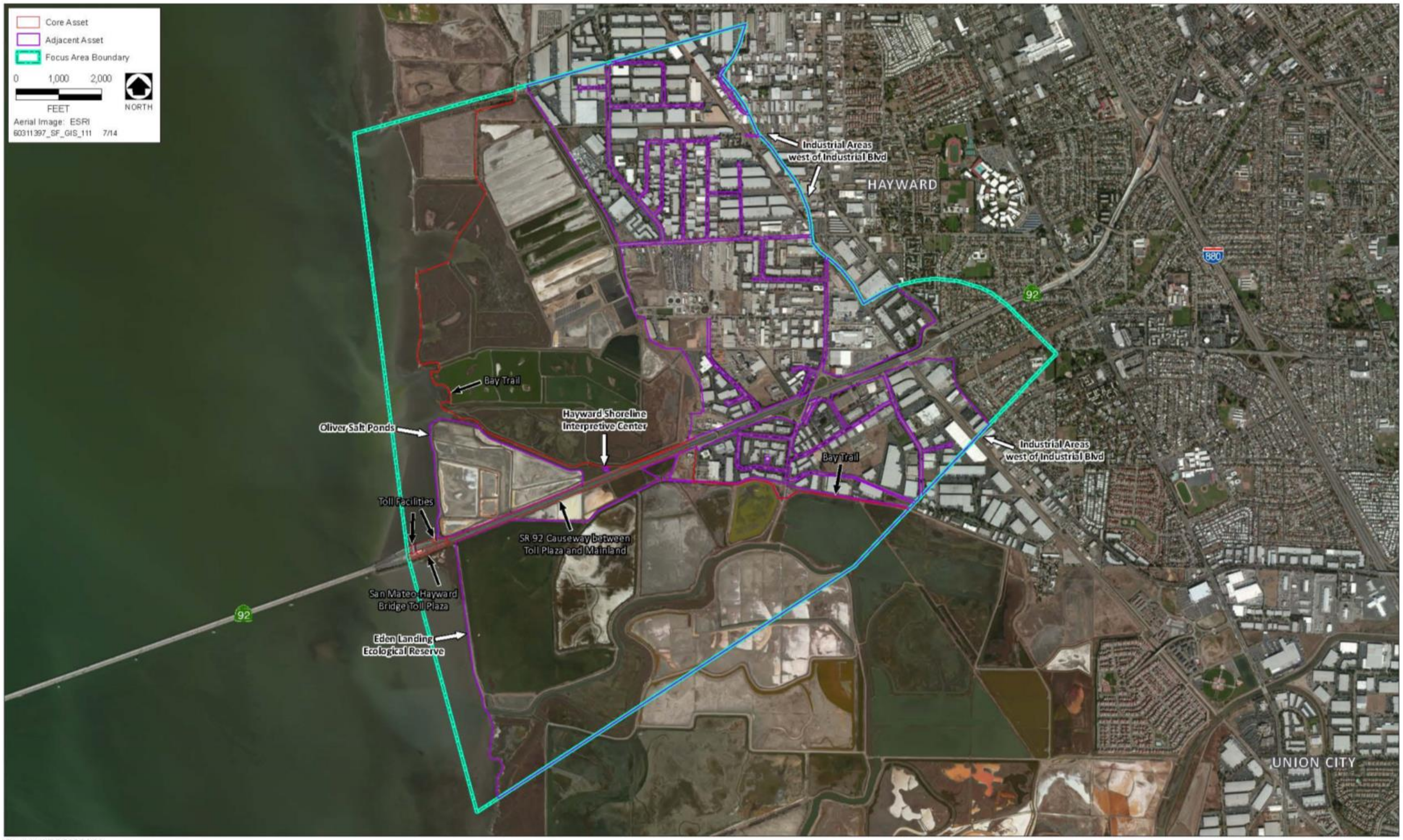
Figure 1-1a: Bay Bridge Touchdown Focus Area

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. 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. 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

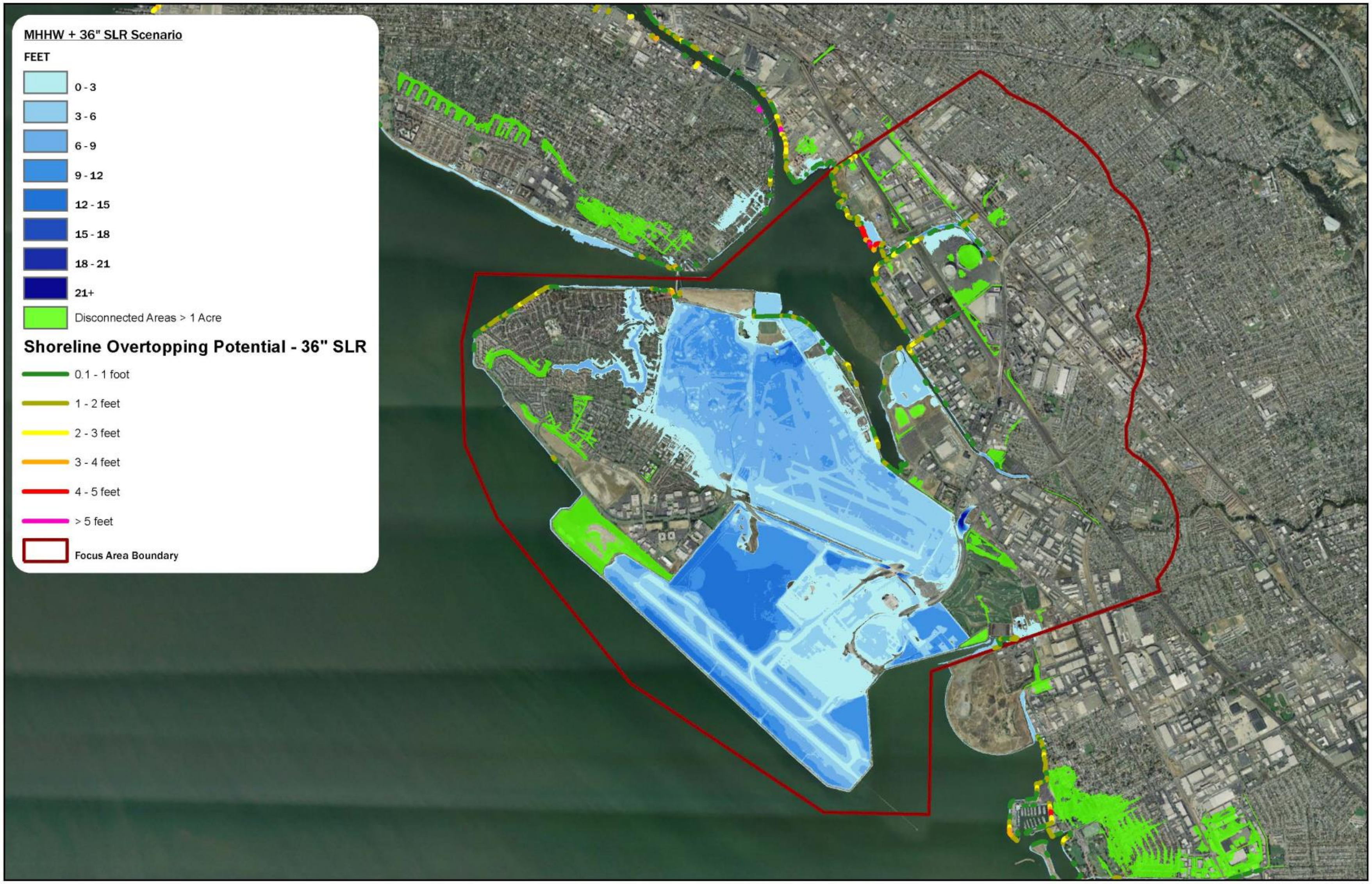
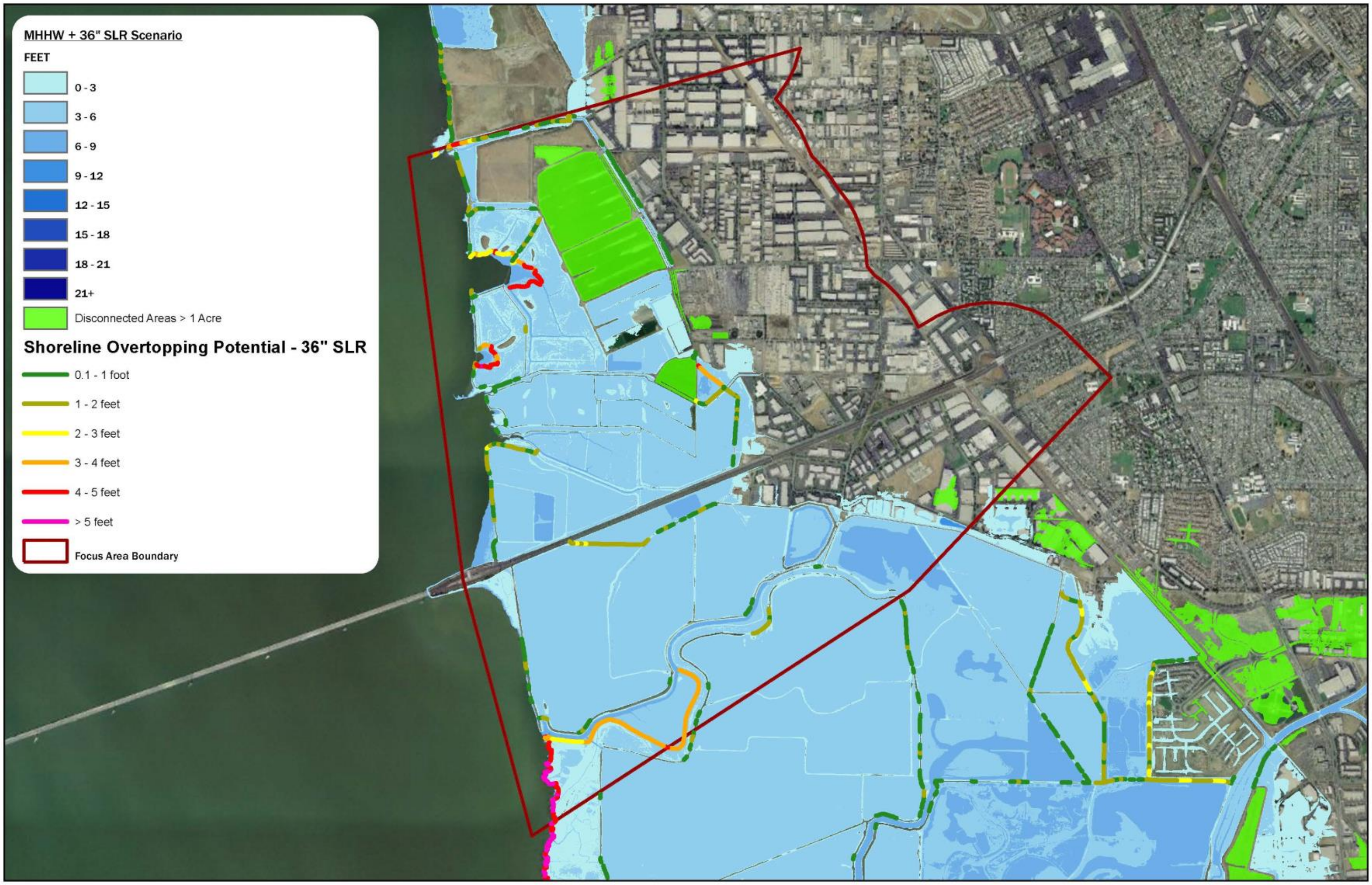


Figure 3-1c: Hayward Focus Area Inundation Map, MHHW + 36-inch Scenario



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

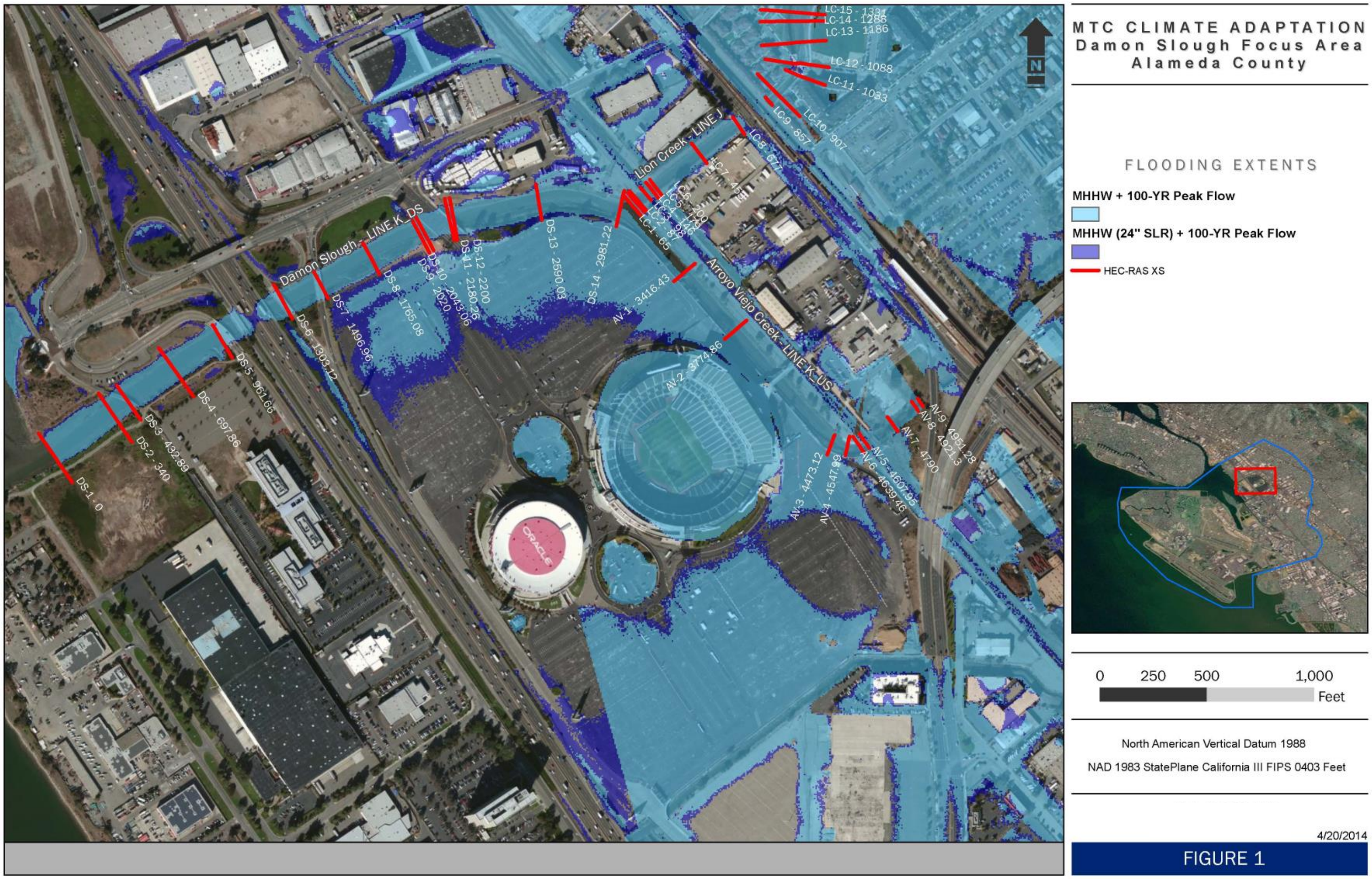
TIDE CONDITION	PEAK FLOW	DESCRIPTION
MHHW	**10-year**	10-year peak flow rate during higher high tide conditions.
+ 12-inch SLR	10-year	10-year peak flow rate during higher high tide conditions with 12-inch SLR.
+ 24-inch SLR	10-year	10-year peak flow rate during higher high tide conditions with 24-inch 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

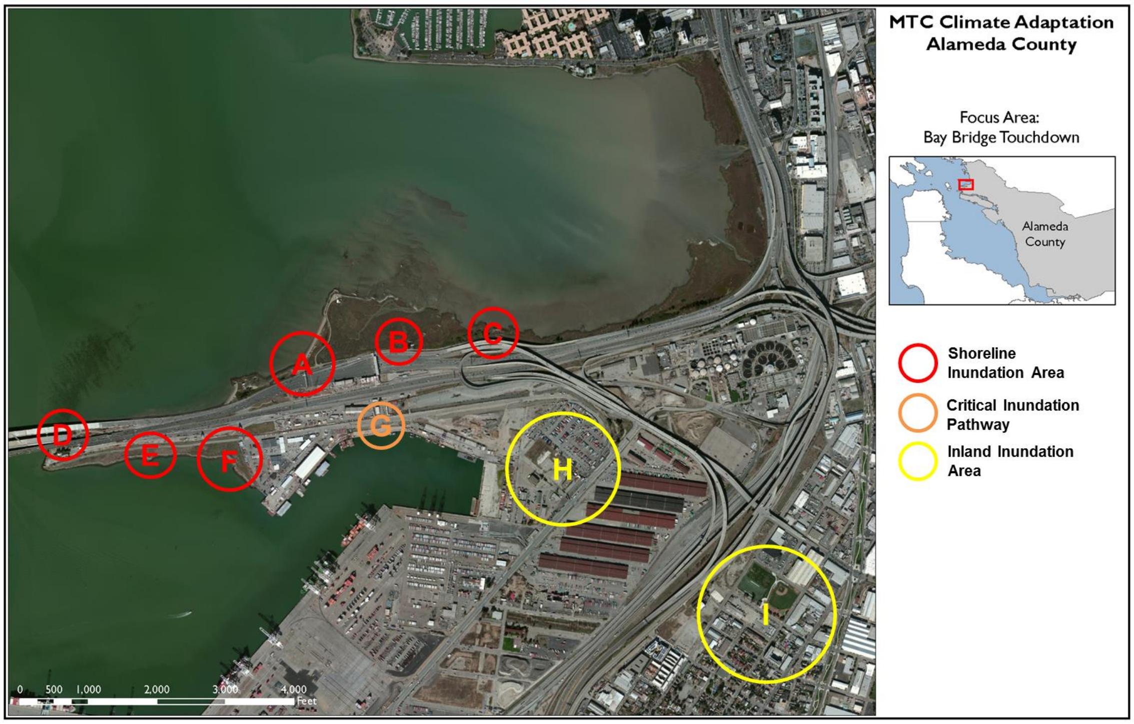


3.3 REFINED EXPOSURE ANALYSIS RESULTS FOR BAY BRIDGE TOUCHDOWN FOCUS AREA

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 **Error! Reference source not found.**.

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

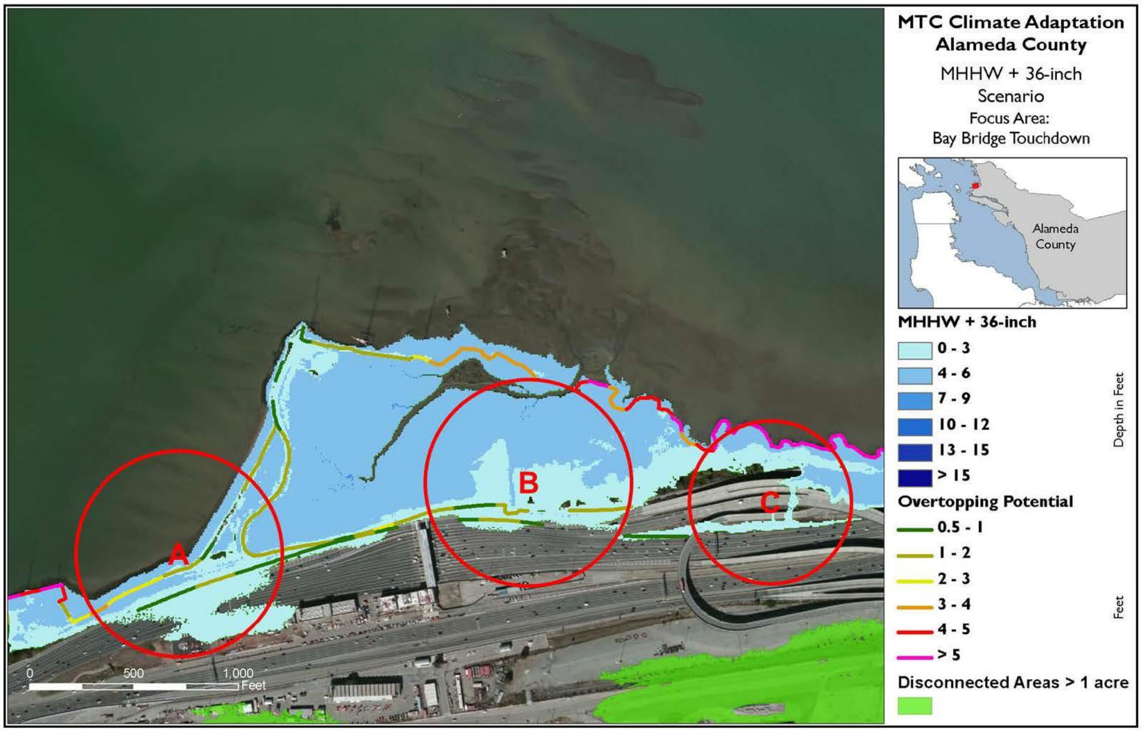
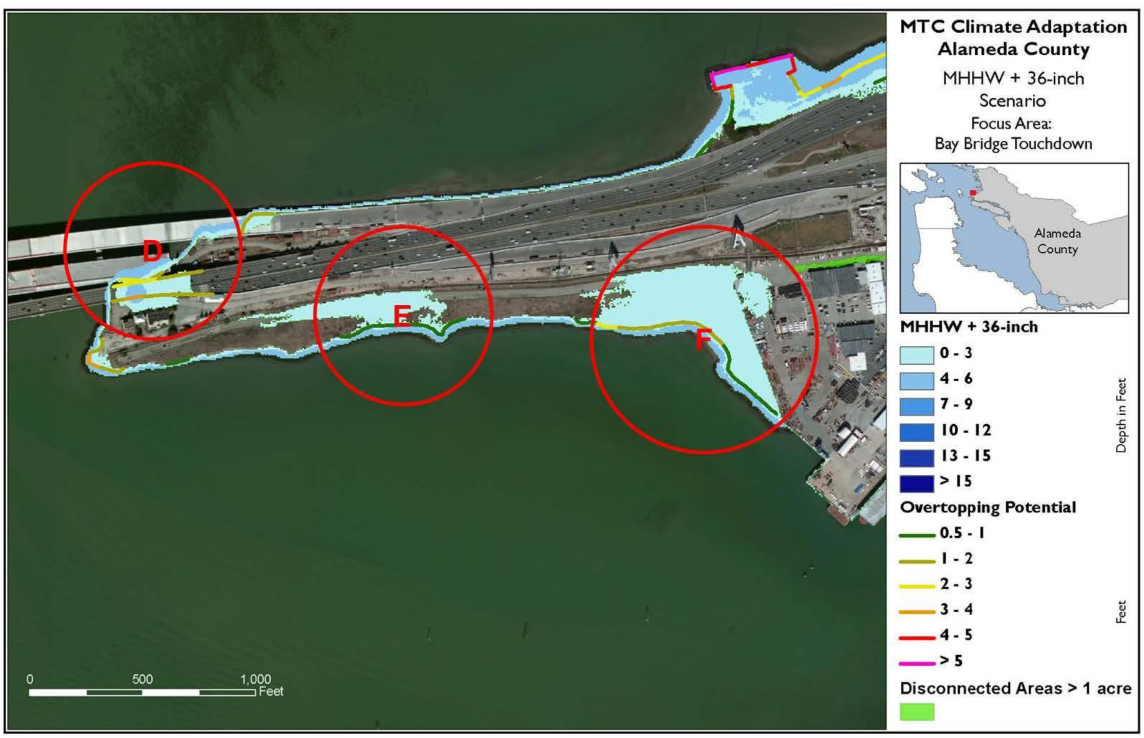


Figure 3-5: Shoreline Inundation Areas D, E, and F - MHHW + 36-inch Scenario



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

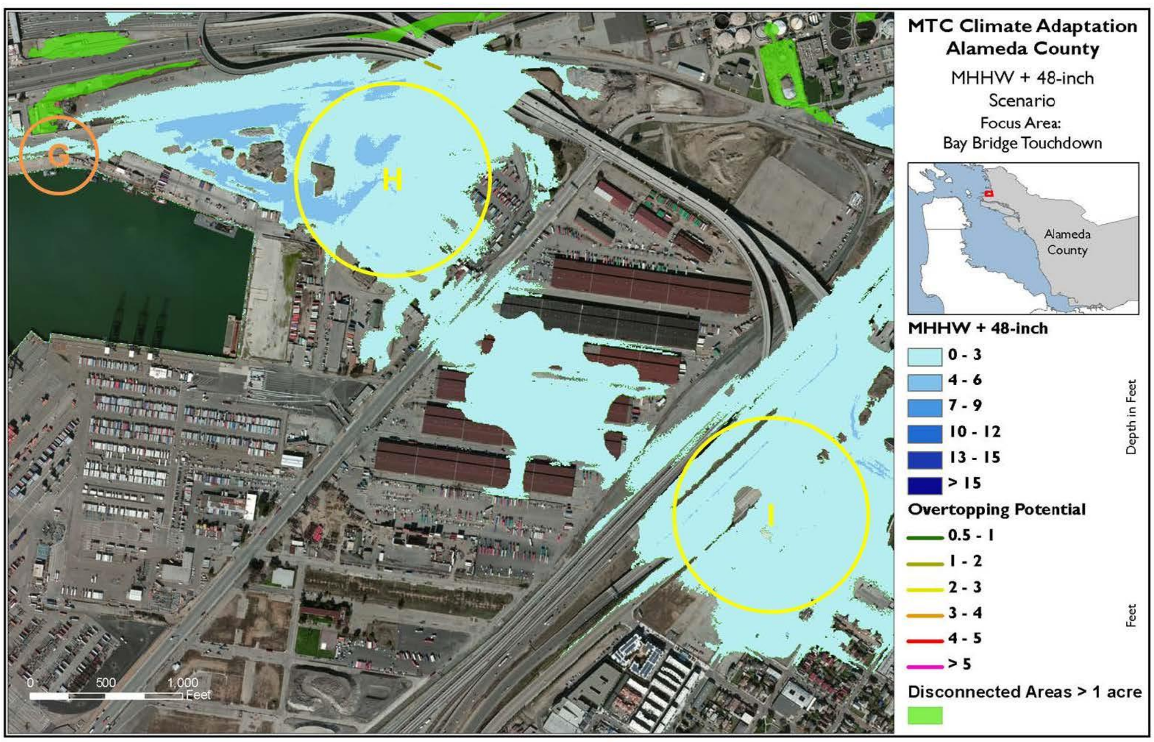


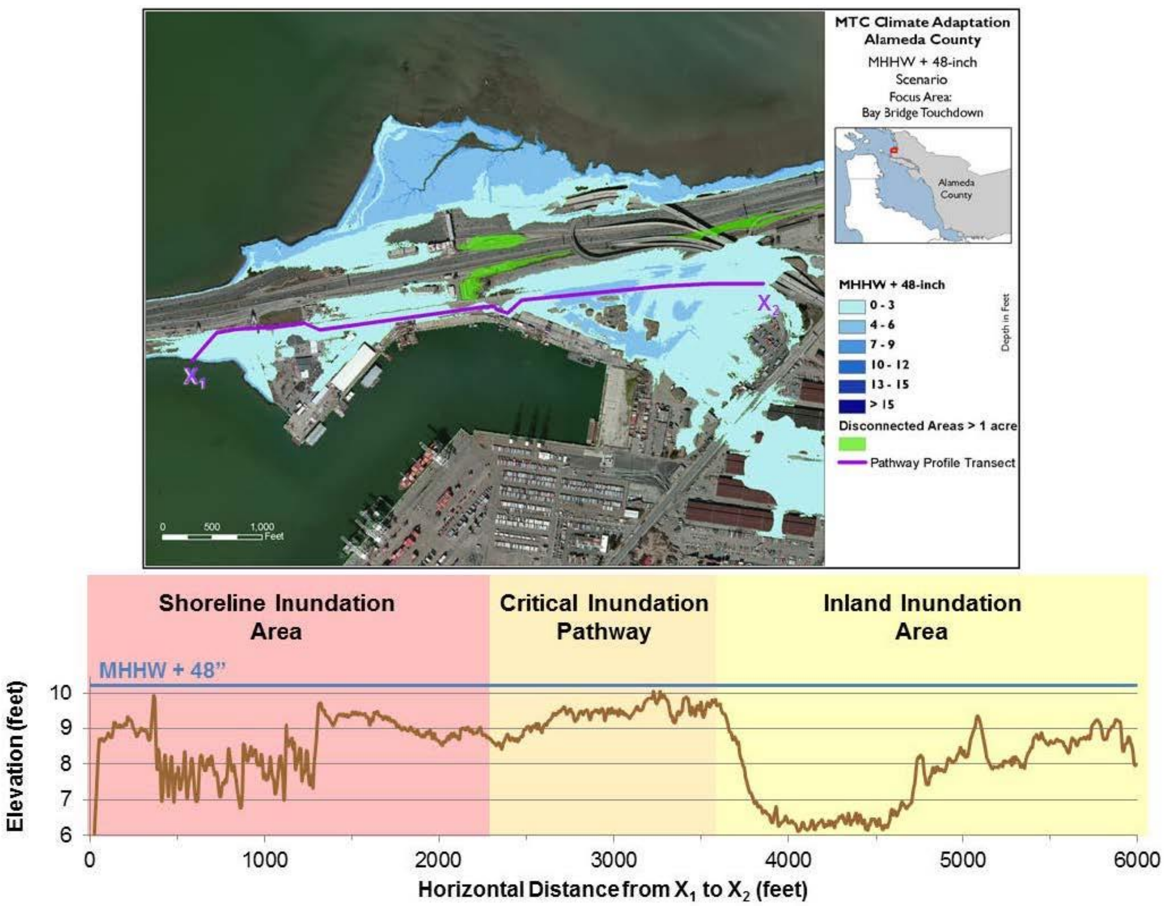
Figure 3-7 shows the elevation profile along the critical inundation pathway starting at the shoreline near Areas E and F and extending inland to Area H. The MHHW + 48-inch water level is shown for reference relative to the topography. As can be seen in Figure 3-7, the MHHW + 48-inch water level overtops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

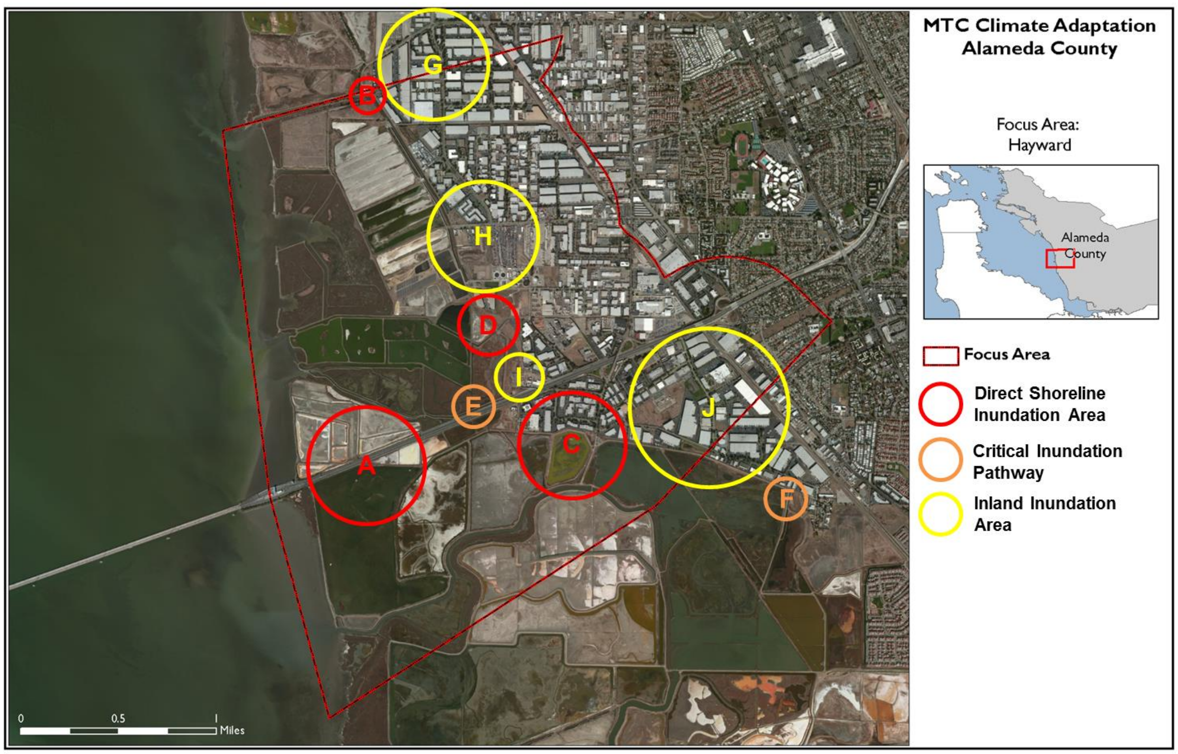


Note: Profile outlined in purple in the plan view. Profile stationing reads from west (X1) to east (X2).

3.4 REFINED EXPOSURE ANALYSIS RESULTS FOR HAYWARD FOCUS AREA

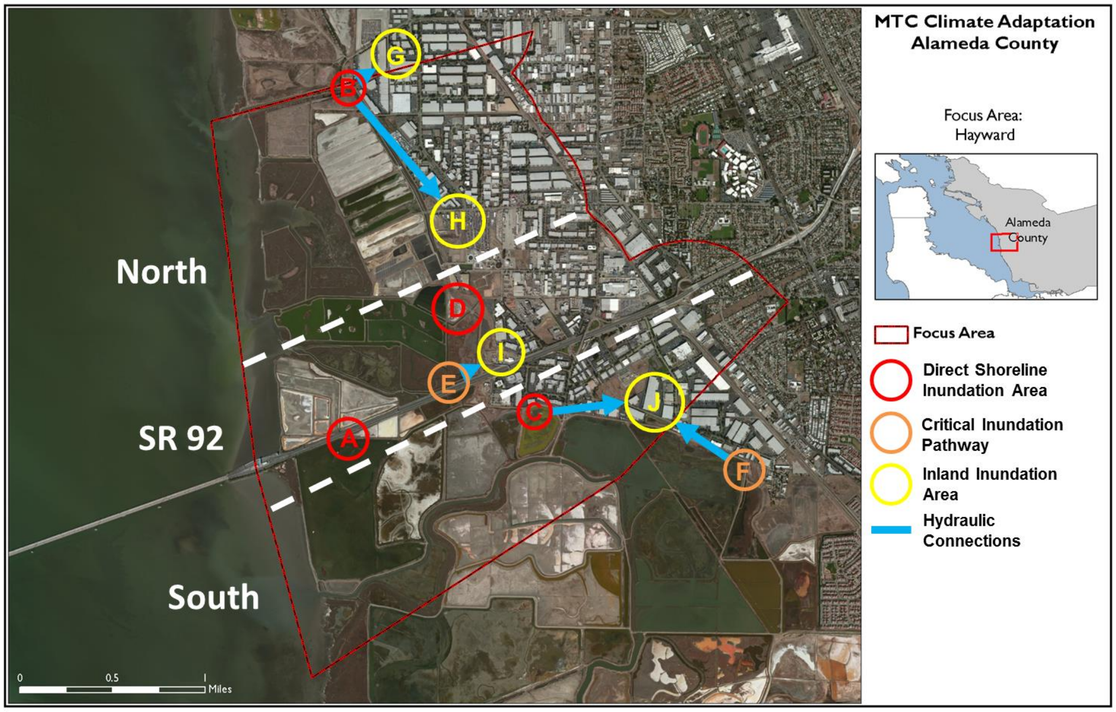
Ten key areas of vulnerability were identified within the Hayward Focus Area based on a detailed review of the inundation mapping. Timing of inundation and proximity to important assets were the fundamental criteria used to select these areas, which are identified in Figure 3-8 and Figure 3-9 and labeled 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

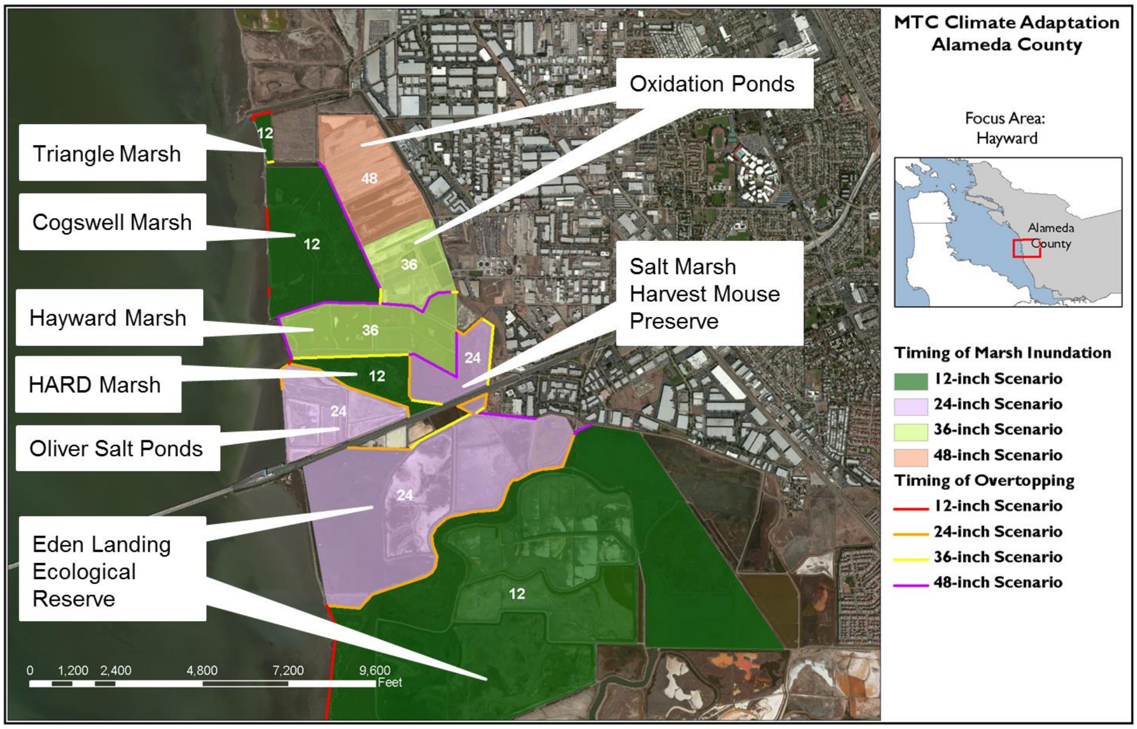


3.4.1 MANAGED MARSHES AND PONDS

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



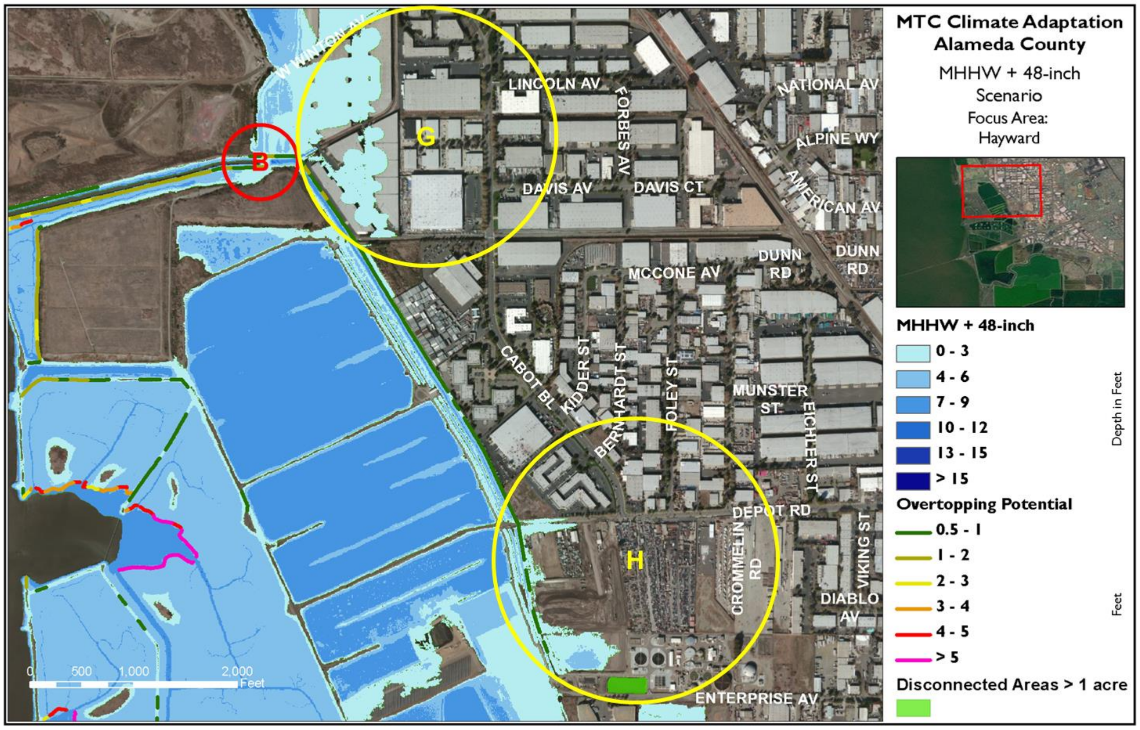
Note: Numbers denote the first SLR scenario that results in inundation (in inches above MHHW).

- 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

- 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 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)
    - Partial inundation of Breakwater Avenue first occurs at the MHHW +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 MHHW +48-inch scenario with inundation depths of 0-3 feet
- Area D (Figure 3-13)
    - 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
    - Antenna towers near Enterprise Avenue are partially inundated

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

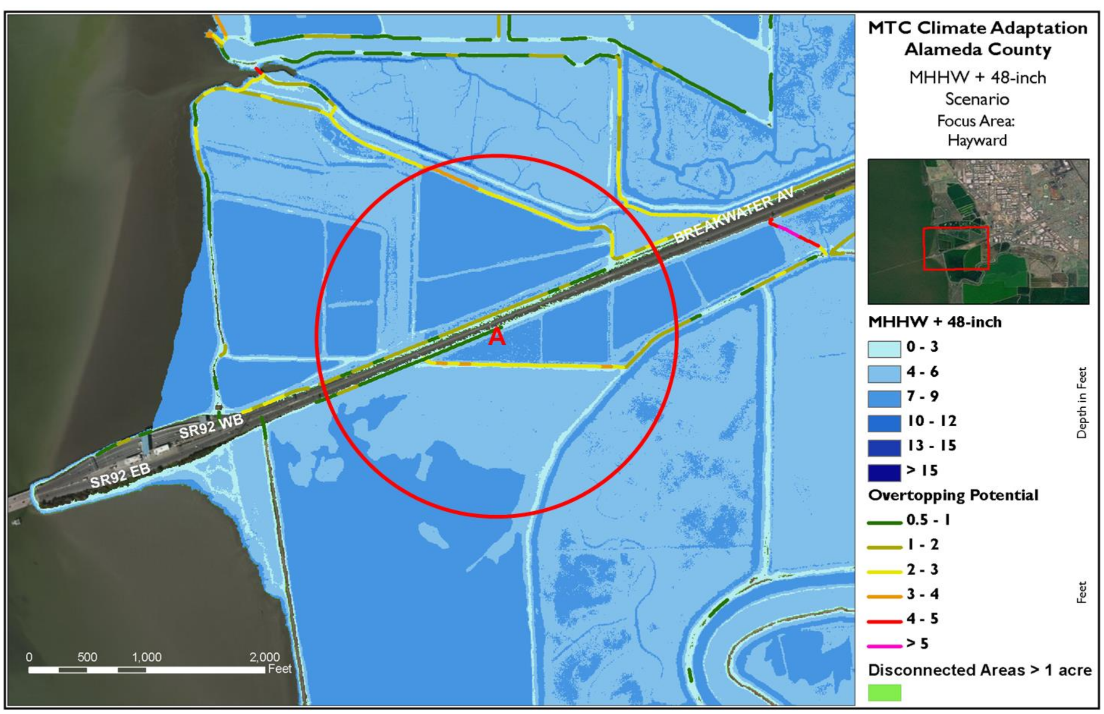
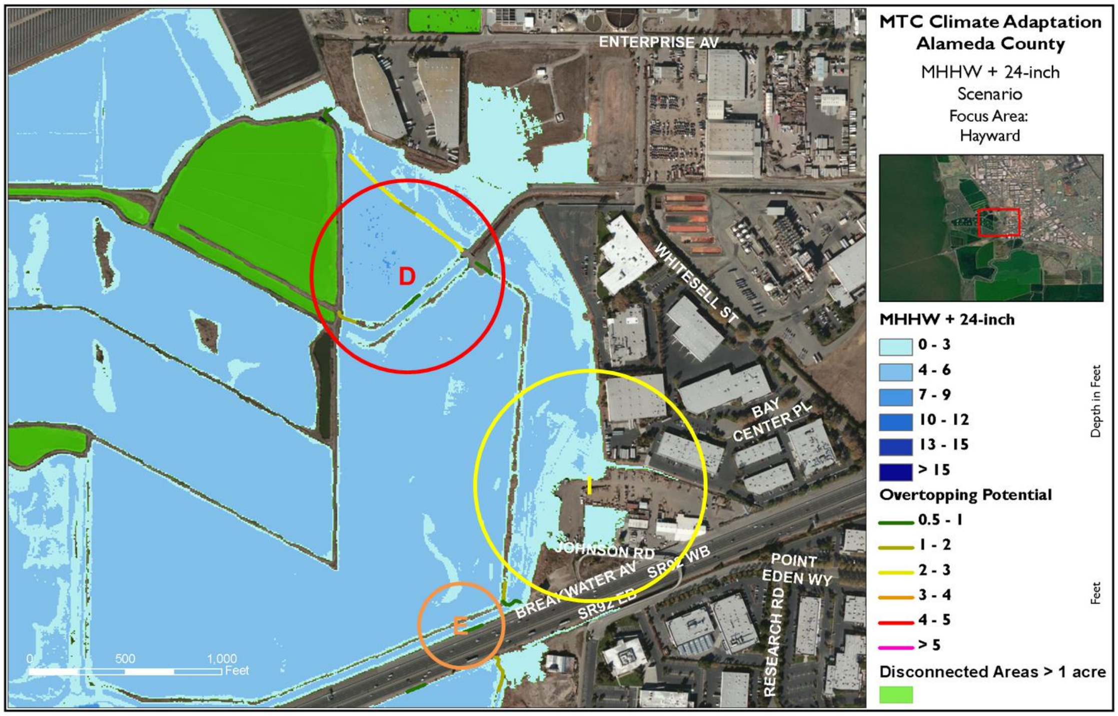


Figure 3-13: Areas of Inundation Adjacent to SR 92 (MHHW + 24-inch Scenario)



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:

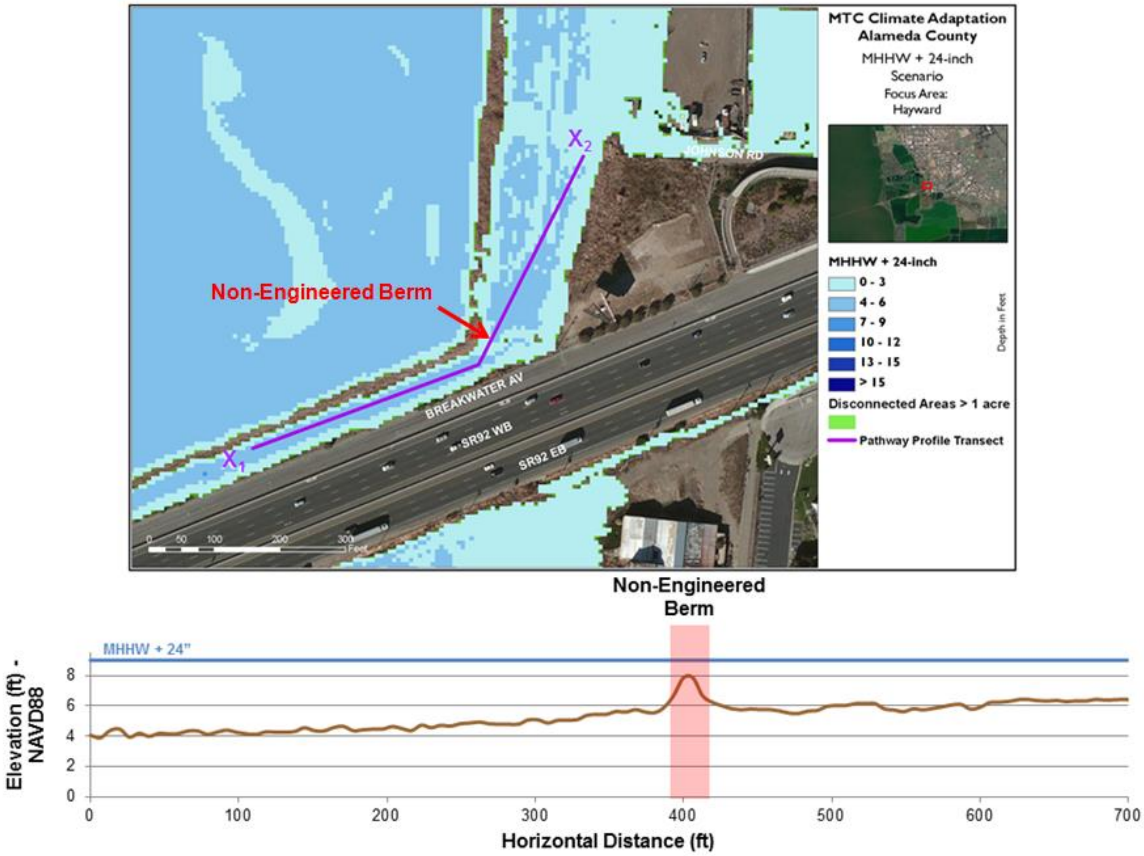
- Area E (Figure 3-13; Figure 3-14)
    - Narrow channel along Breakwater Avenue is inundated, overtopped at the southeast corner of Salt Marsh Harvest Mouse Preserve and connects the flooding from HARD Marsh to inland Area I
    - First occurs at the MHHW +24-inch scenario with inundation depths of 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)

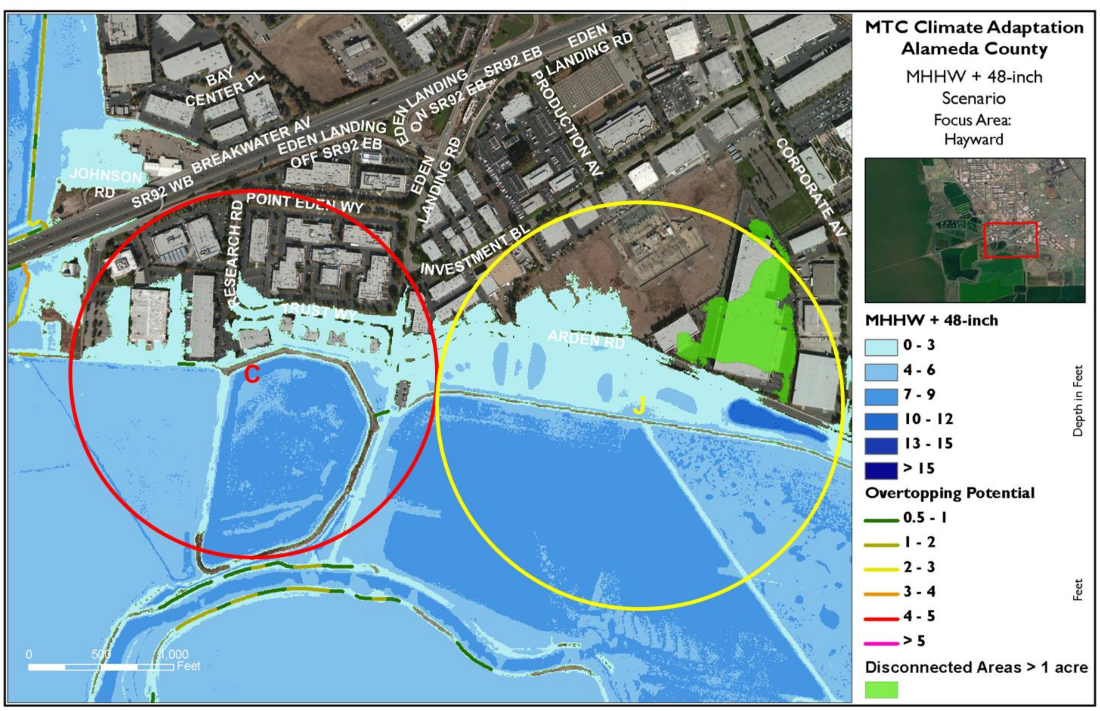


Figure 3-16: Critical Inundation Pathway F & Inland Inundation Area J (MHHW + 24-inch)

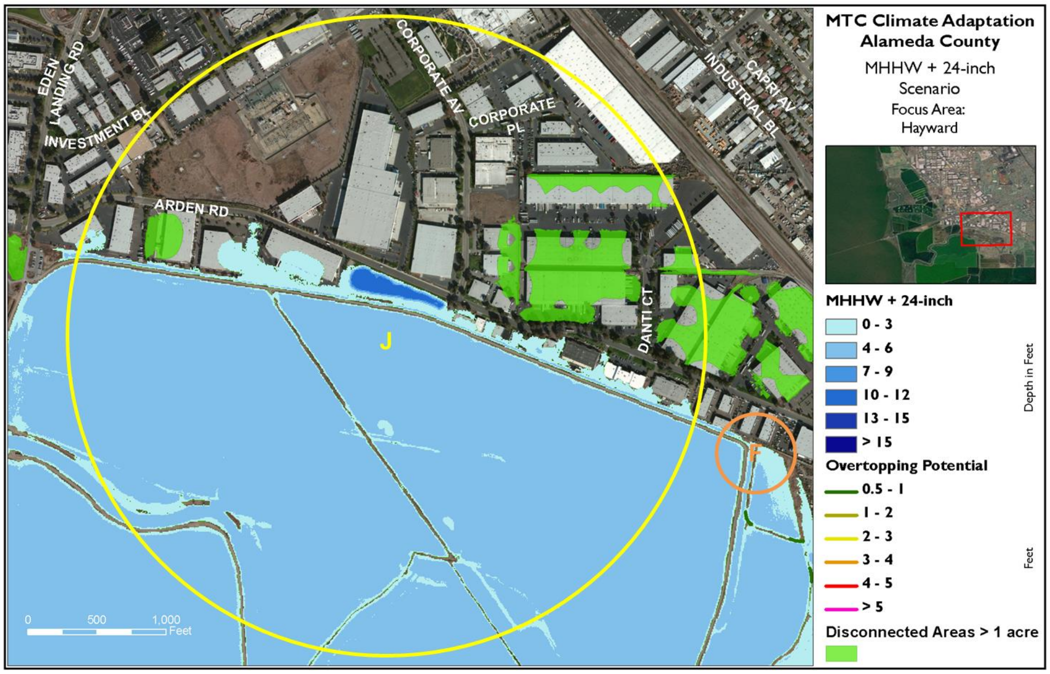
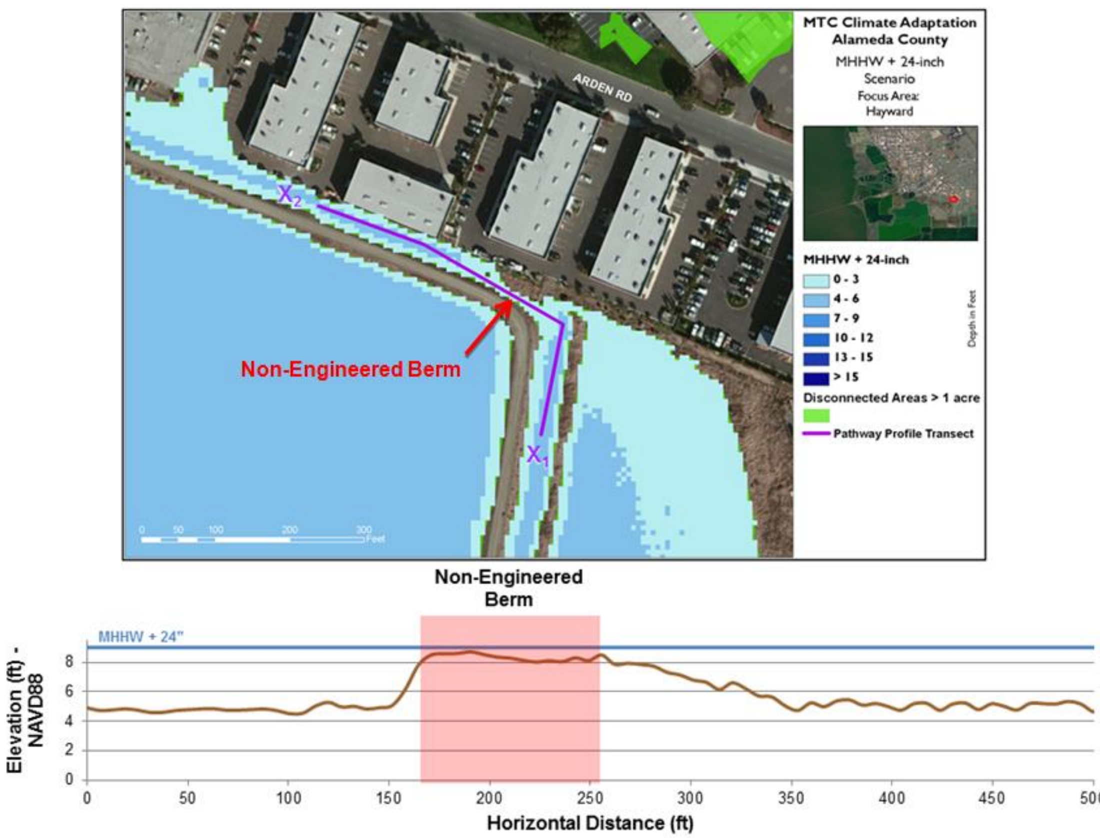


Figure 3-17: Plan and Profile View of Critical Inundation Pathway (Area F) Connecting the Wetland Channel with Inland Inundation Areas



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 7th 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.

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
    - 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:

<u>Governance Strategies</u>

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	Not Specific to one agency	I-880 segment between 7th St and 40th St (supported aerial sections)	Concrete Sealants*	6
	Coliseum		I-880 Damon Slough Bridge		
			Elmhurst Creek Bridge		
Physical	Bay Bridge	Not Specific to one agency	Drainage area around I-80 segment between 40th St and Powell St	Drainage System Modifications*	6
			Drainage area around I-880 segment between 7th St and 40th St		
Physical	Bay Bridge Hayward	Not Specific to one agency	Power-lines in tunnel under toll plaza	Waterproofing Junctions*	6
			SR 92: San Mateo/Hayward Bridge Toll Plaza (1^{st} and 2^{nd} approach) Communication/Power Lines		
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"><u>Project Cost</u></td><td><u>Rank</u></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"><u>Strategy Type</u></td><td><u>Rank</u></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"><u>Strategy Type</u></td><td><u>Rank</u></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"><u>Potential for Integration</u></td><td><u>Rank</u></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><u>Transport Mode</u></td><td><u>Indicator</u></td><td><u>Rank</u></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

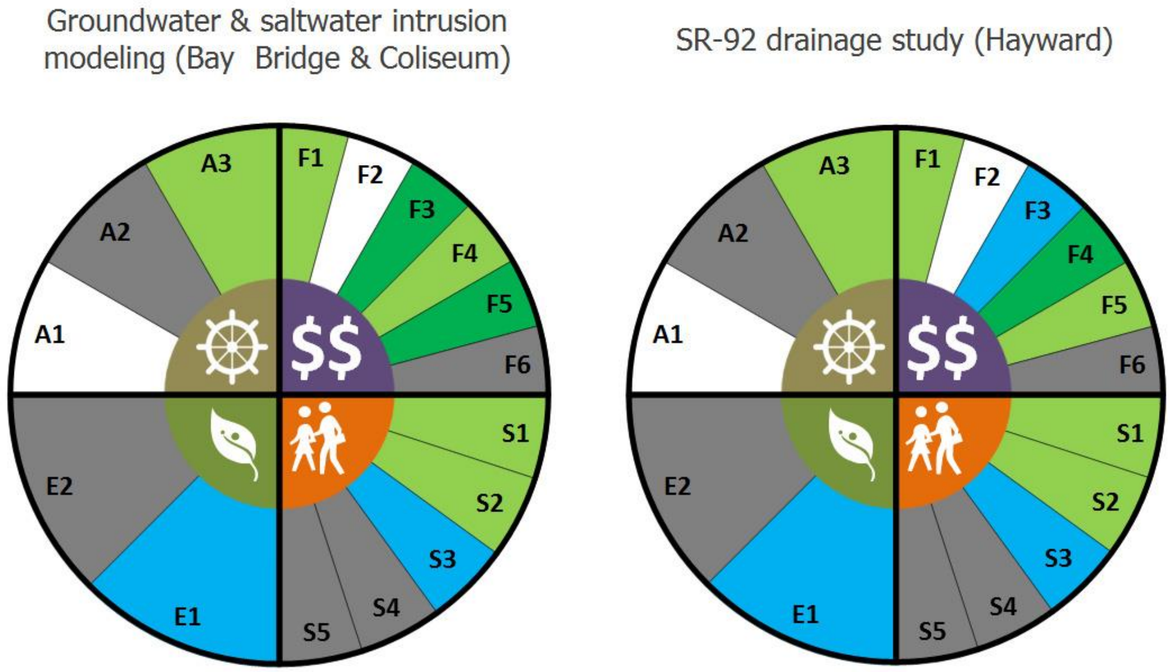


Figure 4-2: Qualitative Assessment Results for Governance Strategies

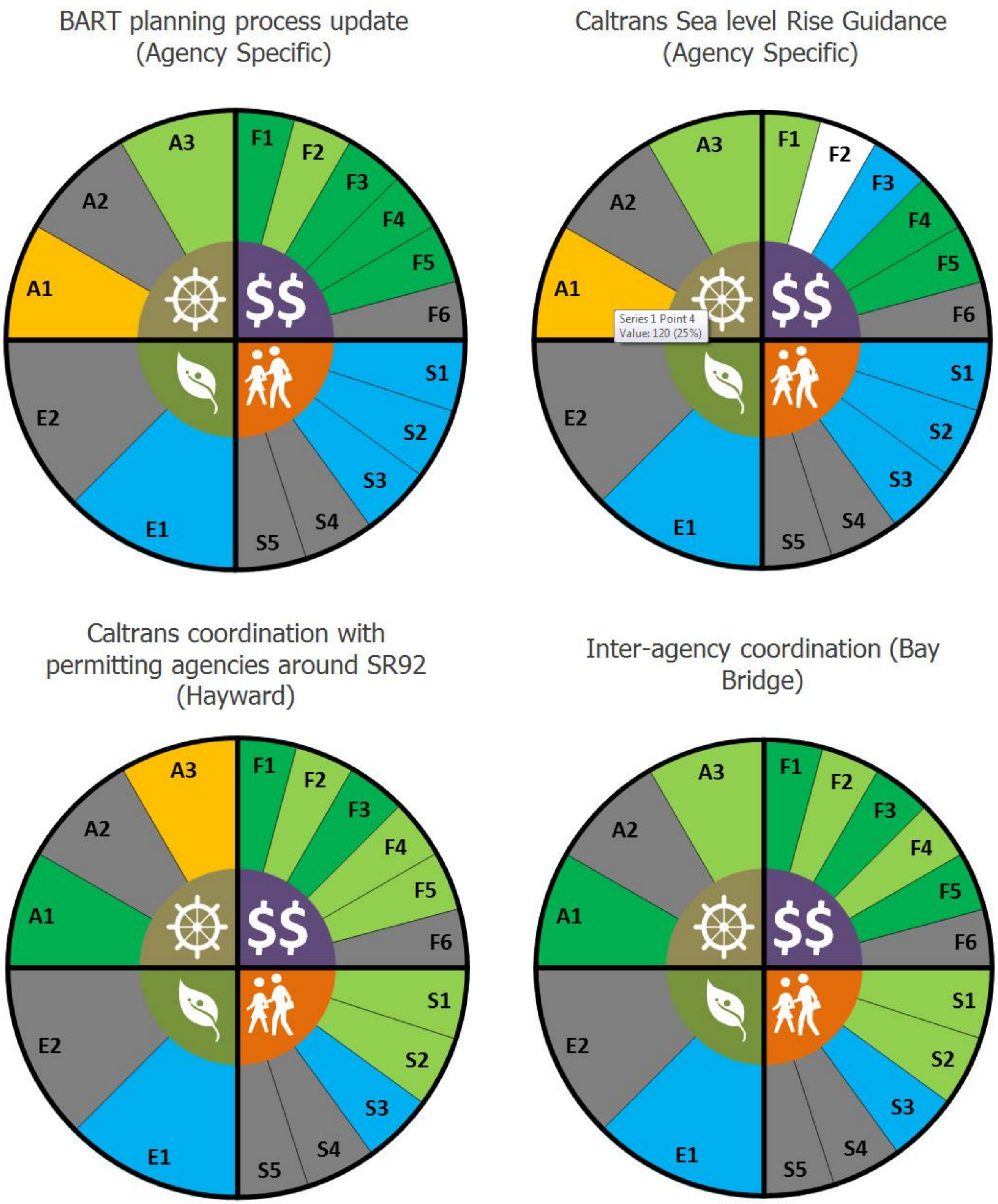


Figure 4-3: Qualitative Assessment Results for Asset-specific Physical Strategies

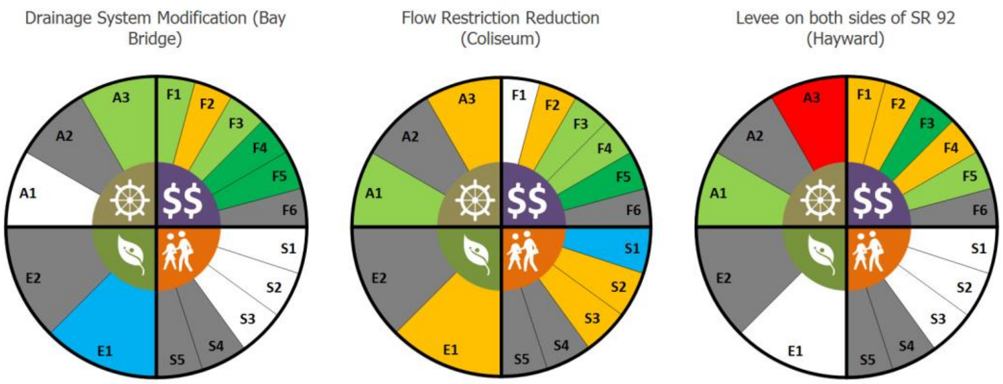
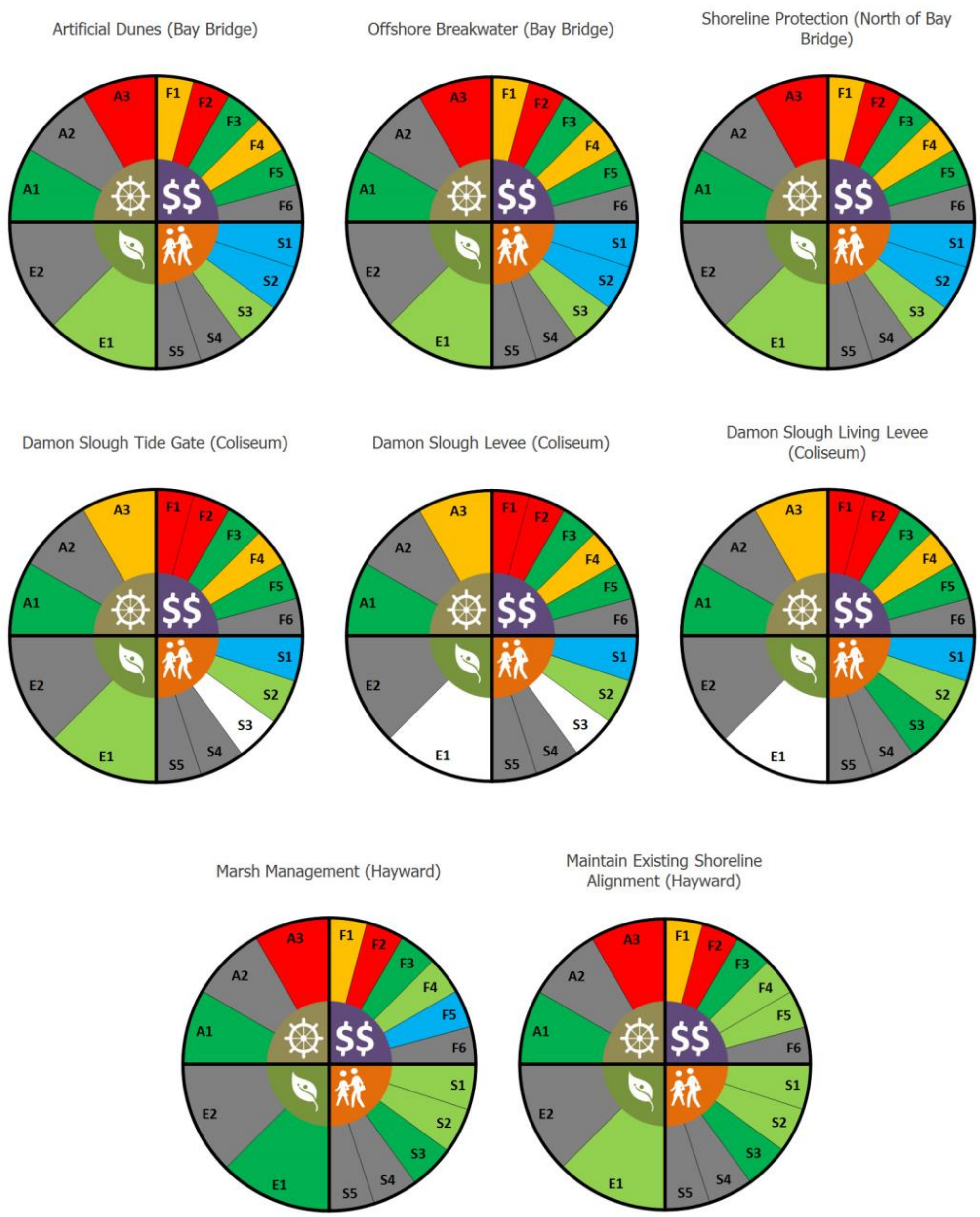


Figure 4-4: Qualitative Assessment Results for Focus area-wide Physical Strategies



- 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)

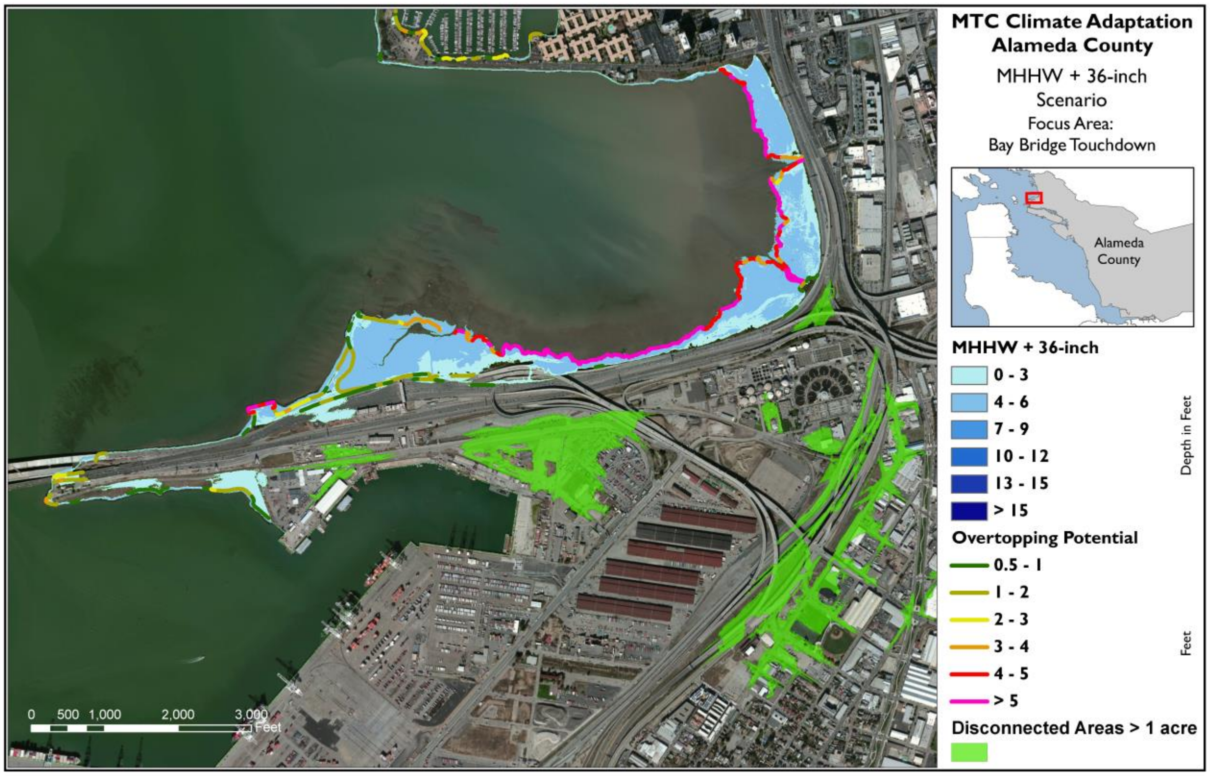


Table 4-7: Roadway segments distributed in Bay Bridge Focus Area

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	54th Ave	Hegenberger Rd	2 of 4 lanes
I-880 NB	54th Ave	Hegenberger Rd	2 of 4 lanes
I-880 NB/SB	7th Street	Grand Avenue	8 lanes
San Leandro Street (Lion Creek)	66th Street	69th Street	7 lanes
San Leandro Street	50th Ave	54th Ave	4 lanes
Hegenberger Road (San Leandro Creek)	San Leandro Street	I-880	4 lanes
98th 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*	66th 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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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

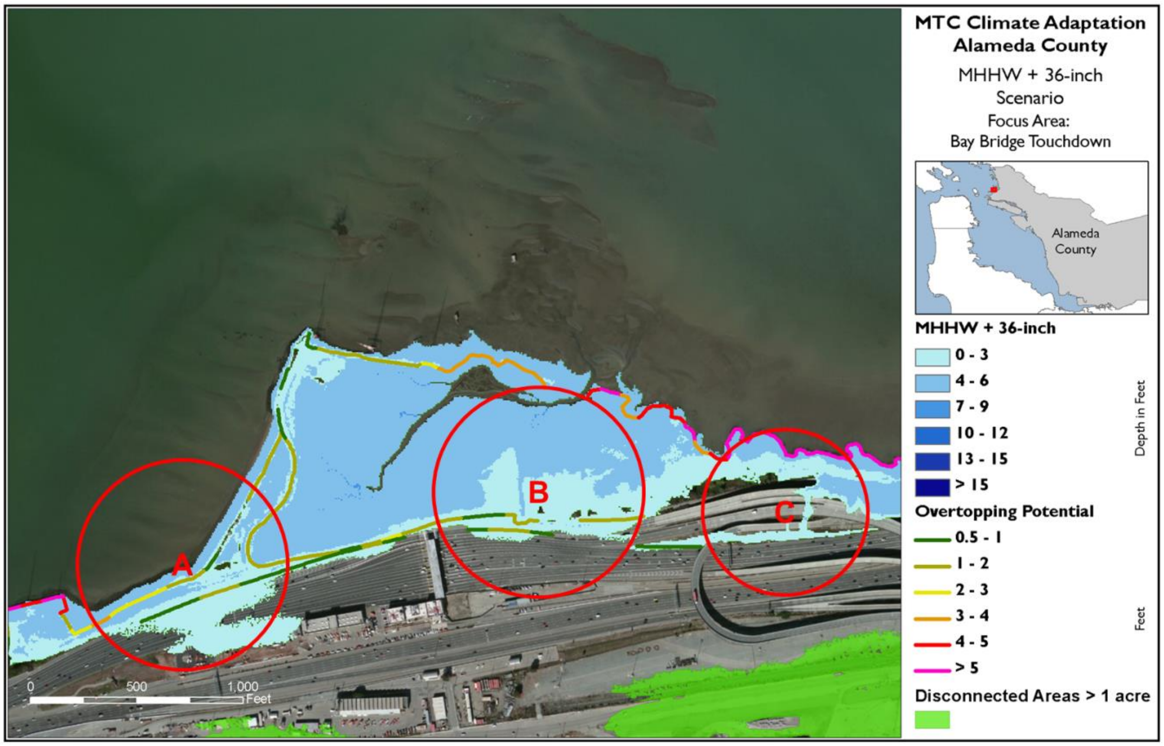
The Bay Bridge touchdown focus area is located south of Emeryville in San Francisco Bay, along the northern boundary of the Oakland Outer Harbor (Figure 5-1). The area includes the Bay Bridge touchdown and westbound portion of the toll plaza as well as the intersection of interstate highways I-580, I-80, 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.

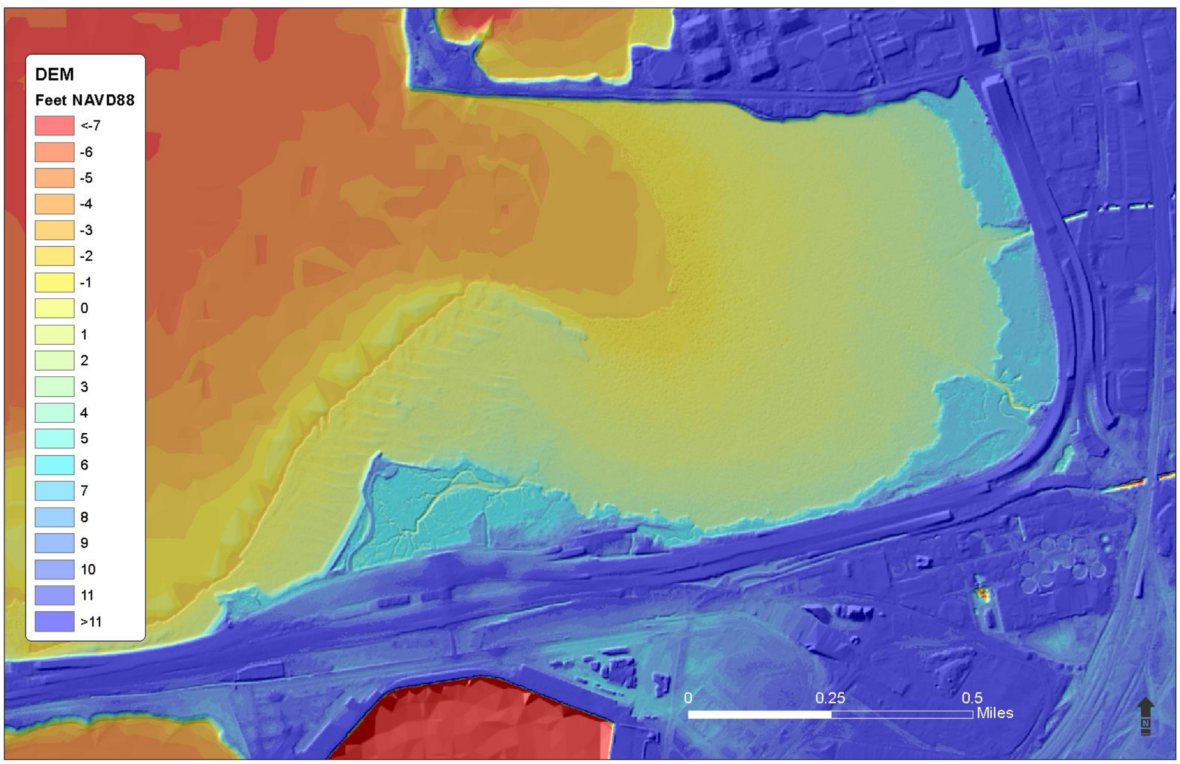
5.2 DEVELOPMENT OF DESIGN CRITERIA

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/

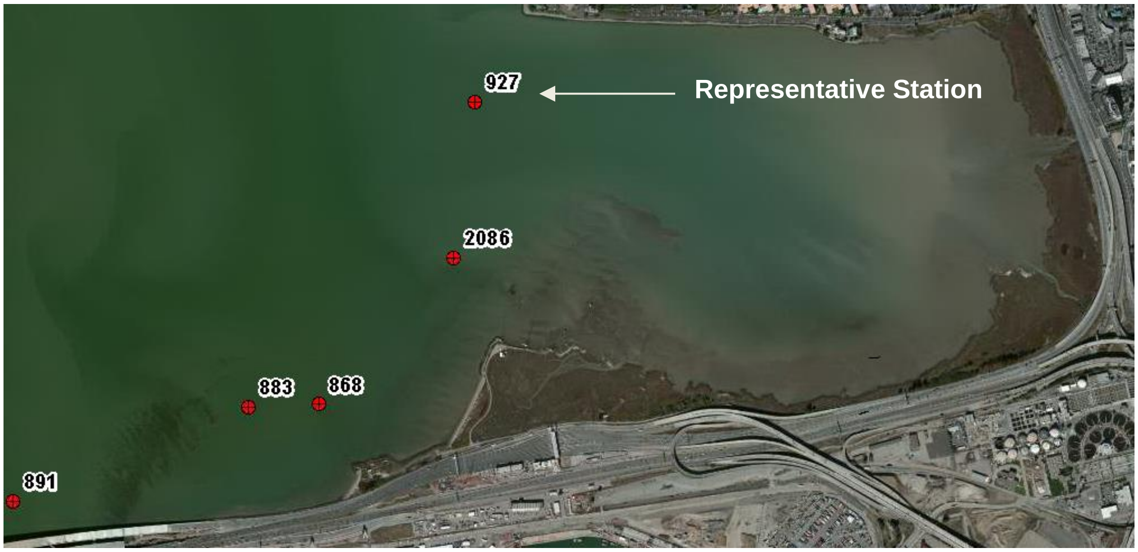
The magnitude of sea level rise that would cause permanent inundation in the area was determined via inundation mapping analysis. As described previously, sites along I-80 in the Bay Bridge Focus Area are expected to be inundated at MHHW with a minimum of 36 inches (3 feet) of SLR (AECOM 2014). For this 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.

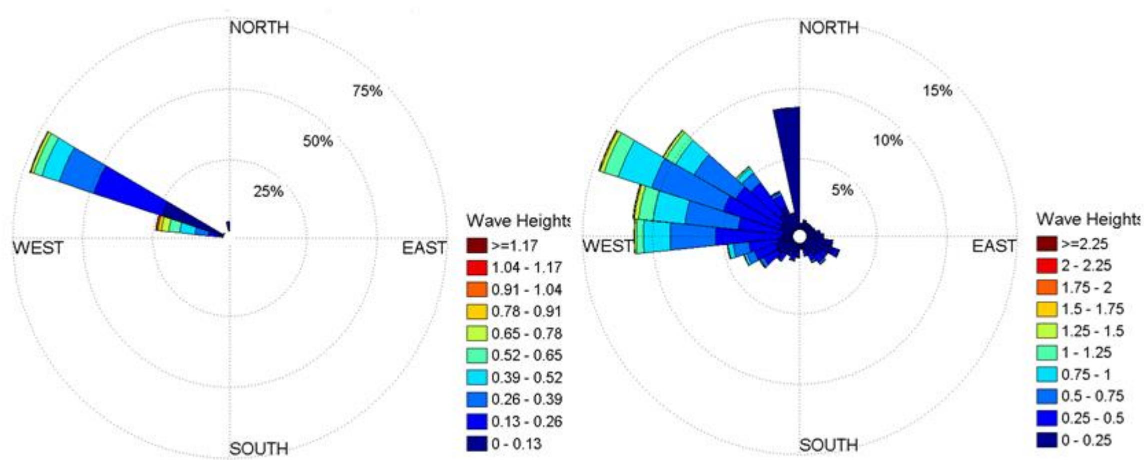
[44] The term “swell” is used to describe to describe a specific type of wave. Swells are waves not produced by the local wind and come in at a higher period (longer wave length) than waves produced by the local wind.

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



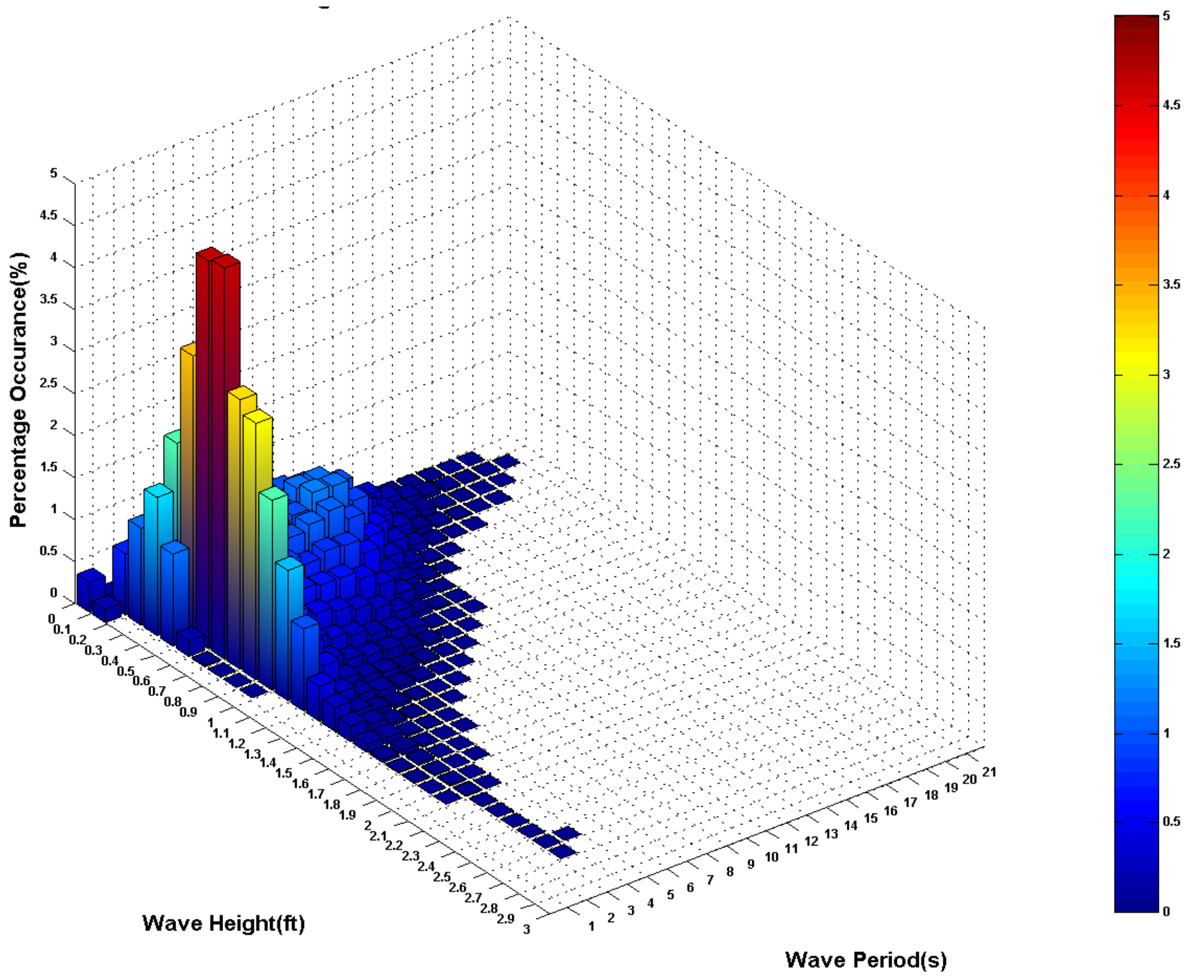
This area is only exposed to swell and seas that approach from the northwest and it is protected from swell and seas that approach in all other directions (**Error! Not a valid bookmark self-reference.**). Swell significant wave heights (H_S) at Station 927 range from approximately 0 - 1.2 feet and seas 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 (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 (**Error! Not a valid bookmark self-reference.**). 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). 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)

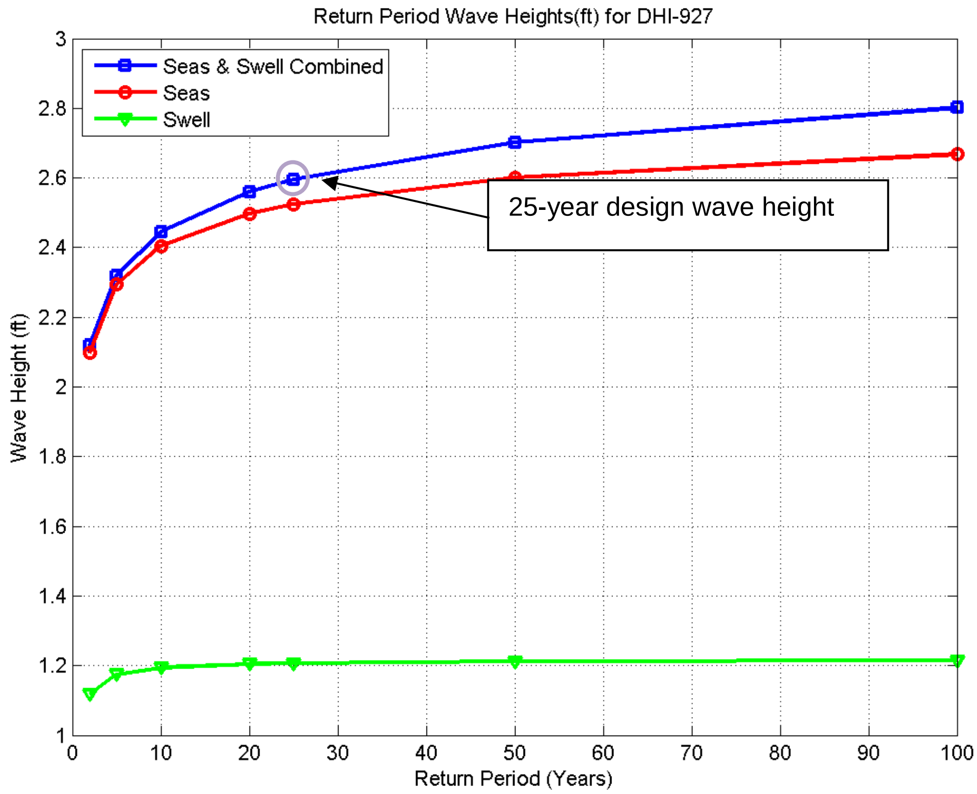


Table 5-2: Design Wave Conditions

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 and the design of the breakwater is described in Section 5.3.2.

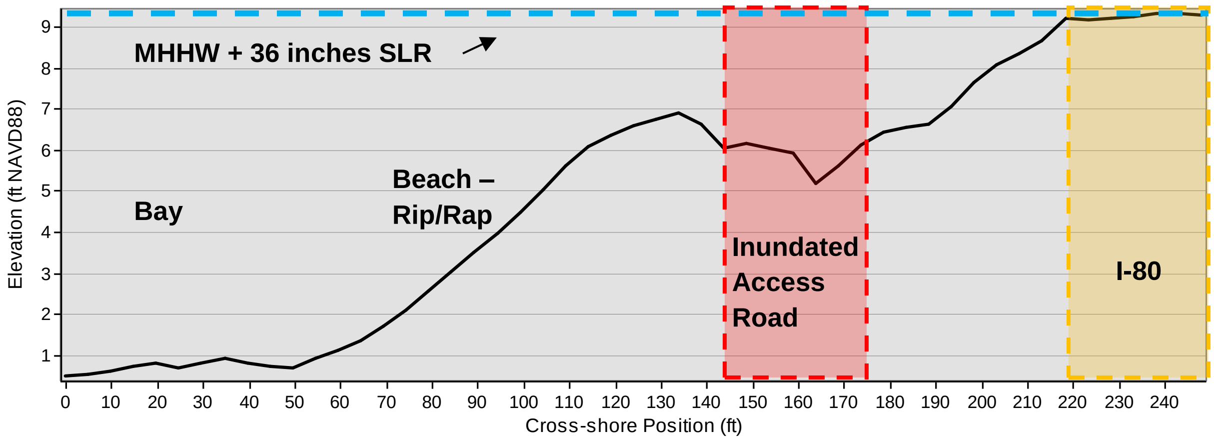
5.3.1 CONCEPTUAL DESIGN OF THE LIVING LEVEE

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.

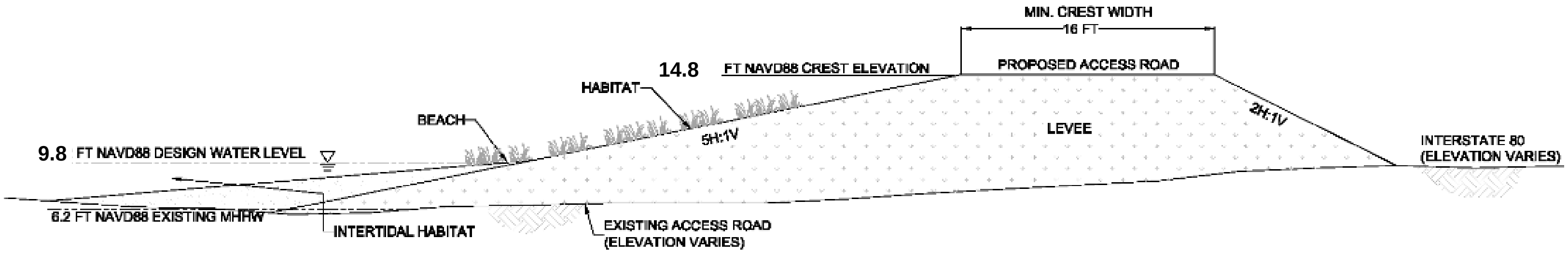
Figure 5-10: Approximate footprint of the living levee designed to protect I-80 from inundation under 36 inches of SLR. This particular placement will protect the three inundated (sites A, B, C in Figure 5-2)

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

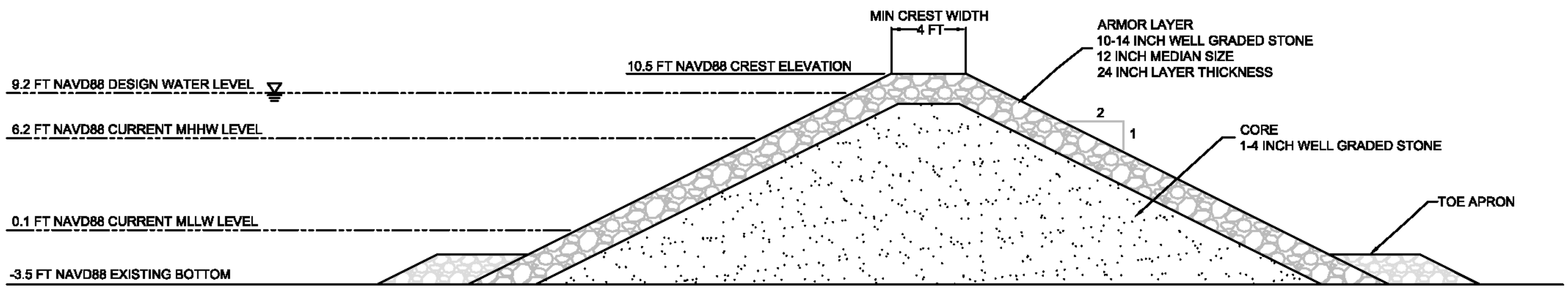


Table 5-6: Summary of the Breakwater Freeboard Calculation Following the CEM (USACE 2012)

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 erode 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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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 0. 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

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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.

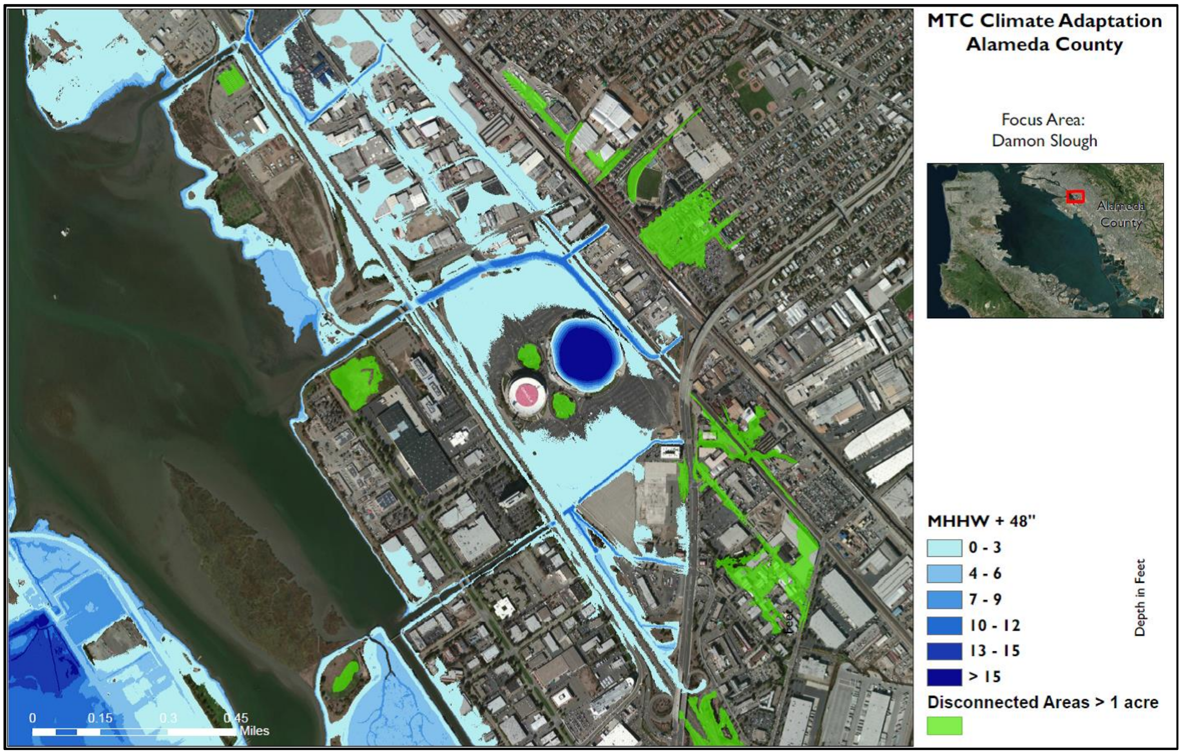
The shoreline is characterized by intermittent salt marshes and mudflats; rip-rap installed for shoreline protection, and vegetated banks. Damon Slough runs adjacent to the Oakland Coliseum and drains directly into San Leandro Bay. The slough is fed by its upstream tributaries Arroyo Viejo Creek and 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.

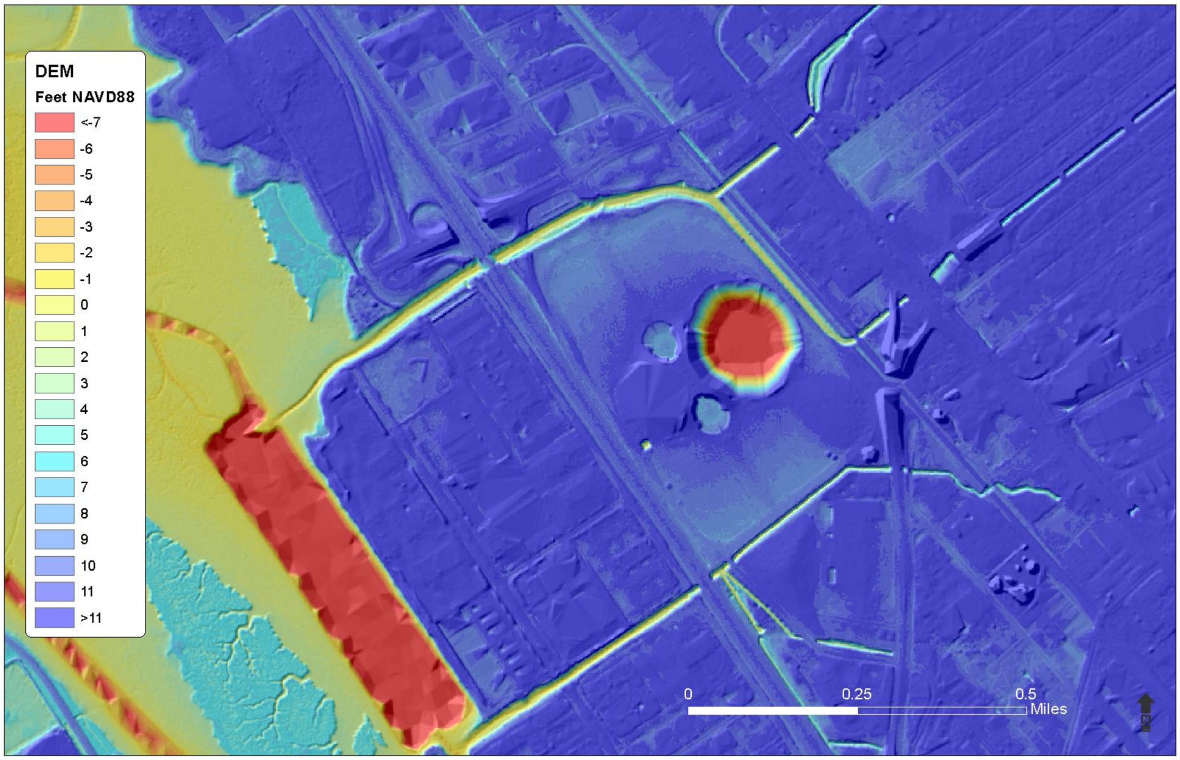
6.2 DEVELOPMENT OF DESIGN CRITERIA

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 0.

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.

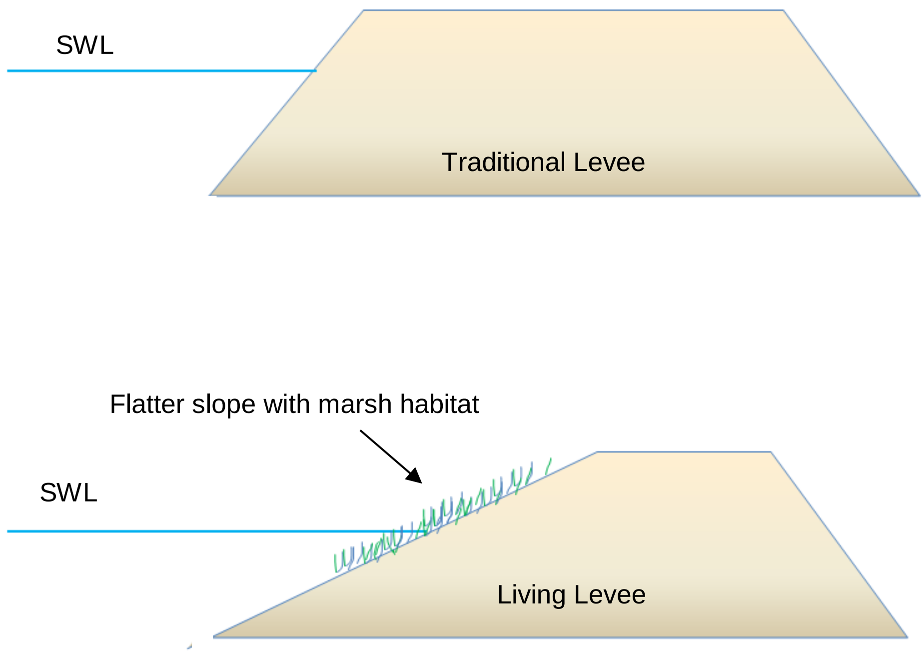
6.3.1 CONCEPTUAL DESIGN OF THE LIVING LEVEE

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.

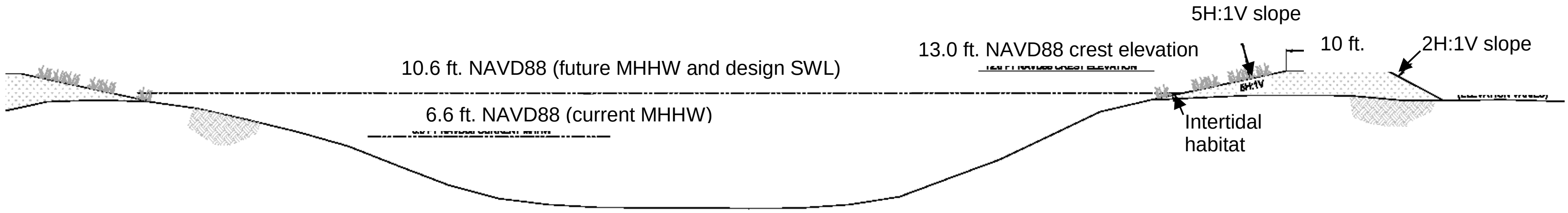
It is important to note that in areas where the living levee footprint encroaches on a critical asset that cannot be impacted, a segment of traditional levee with a smaller footprint can be constructed.

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

AECOM 2014. *Oakland Coliseum – Damon Slough/Arroyo Viejo Creek*. Technical memorandum prepared for MTC Climate Adaptation Pilot Study.

AECOM 2014. *Bay Farm Focus Area*. Technical memorandum prepared for Oakland International Airport/Bay Farm Island Focus Area Shoreline Resilience Planning Project being led by ABAG and BCDC.

BakerAECOM 2013. *Central San Francisco Bay Coastal Flood Hazard Study*. Technical report prepared for FEMA.

BCDC 2011. *Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project*. Technical report accessed at http://www.mtc.ca.gov/planning/climate/RisingTides-TechnicalReport.pdf.

CDWR 2012. Urban Levee Design Criteria. Technical report prepared for the State of California

DHI 2011. Regional Coastal Hazard Modeling Study for North and Central Bay. Technical report prepared for FEMA.

USACE 1994. *Engineering Manual*. Technical Report.

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]

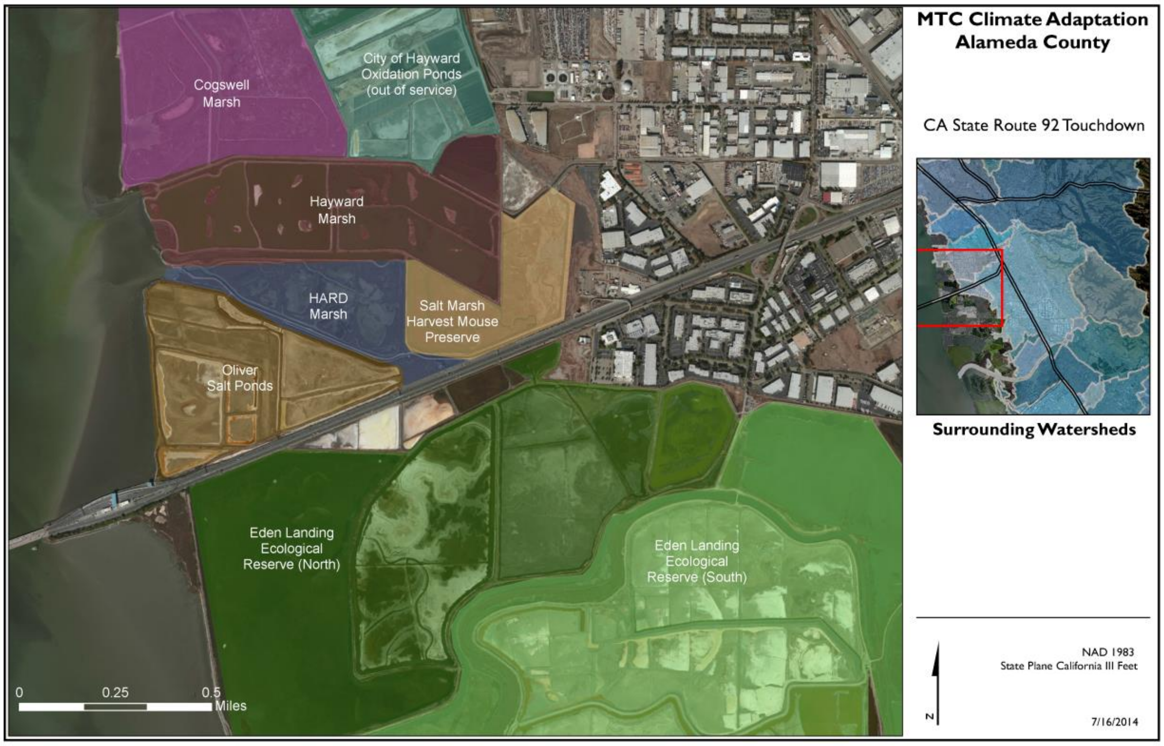
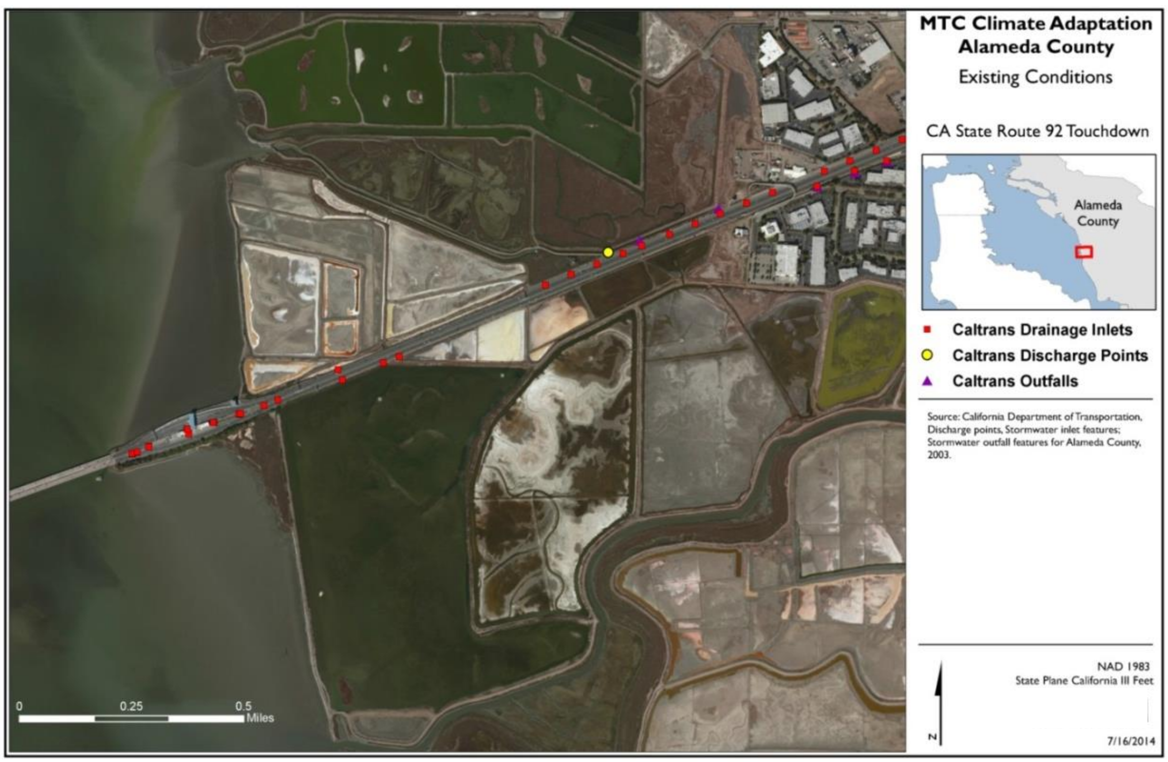


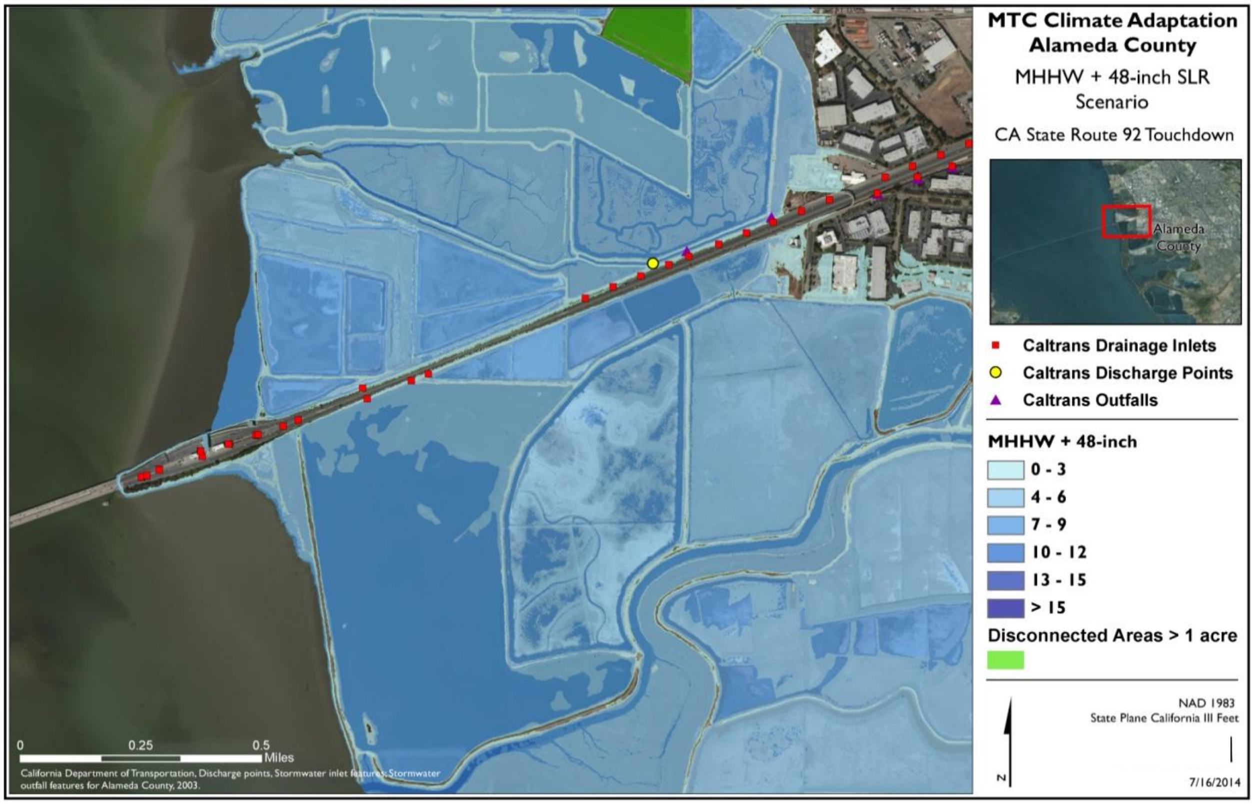
Figure 7-2: SR 92 Touchdown Caltrans Drainage Structures[64]



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)

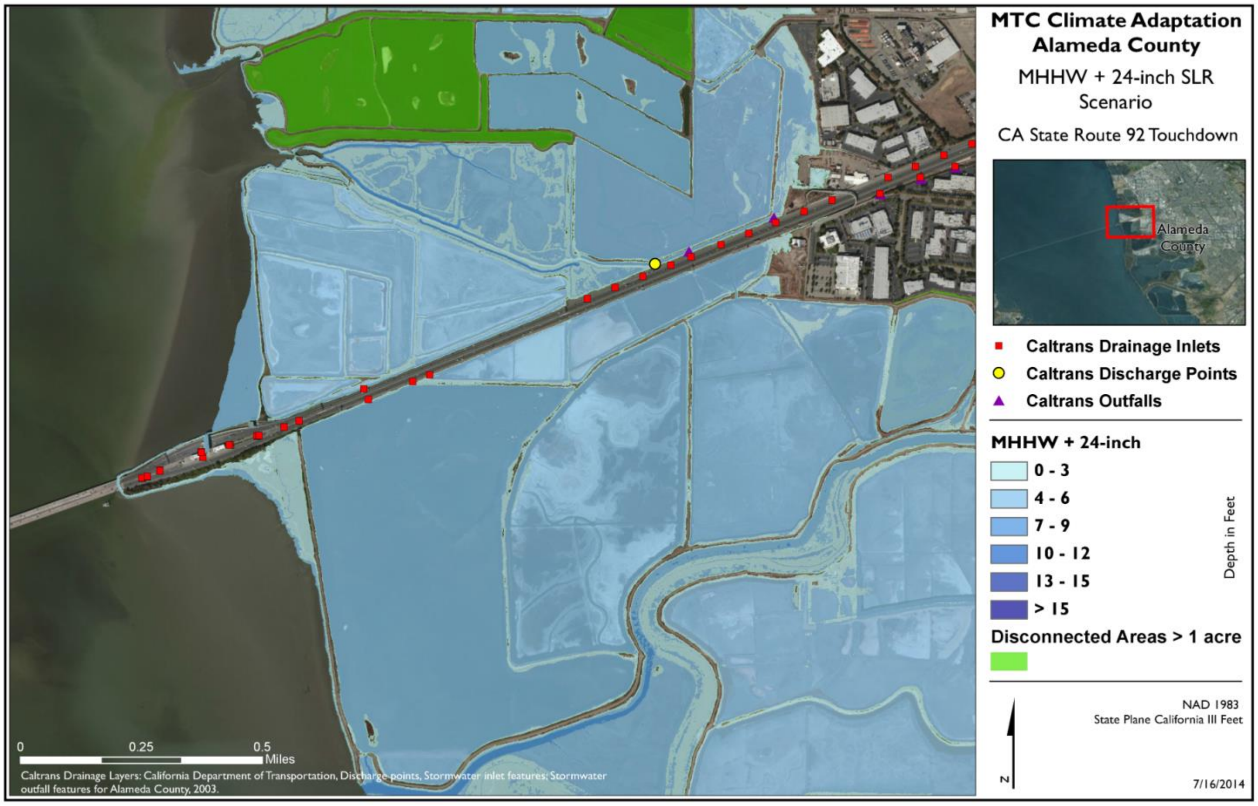
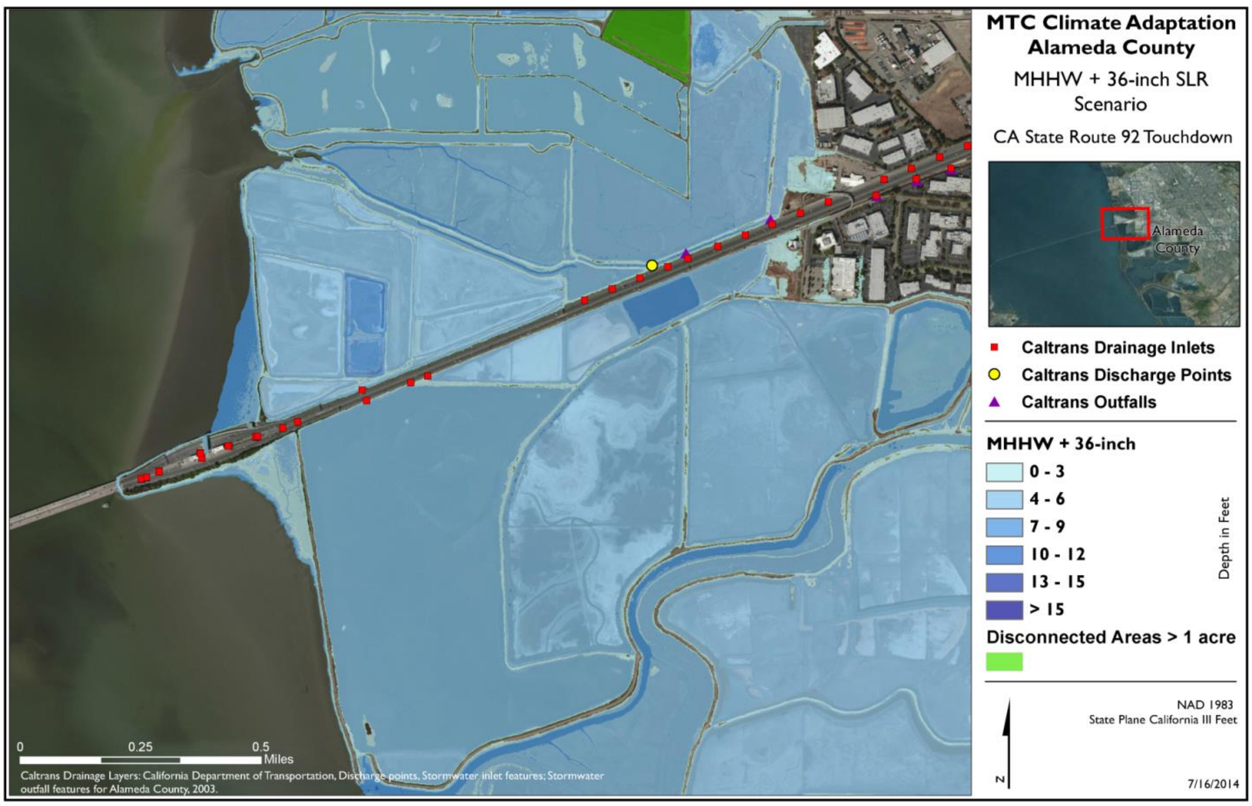


Figure 7-5: Inundation at SR 92 Touchdown (MHHW+ 36-inch Scenario)



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 State 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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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.

<u>Informational Interdependencies</u>

- **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.

<u>Operations & Maintenance</u>

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.

<u>Informational Interdependencies</u>

- **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. 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. 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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