APPENDIX

Adapting to Rising Tides

Transportation Vulnerability and
Risk Assessment Pilot Projectt

Technical Report • November 2011

Appendix A – Accompanying Chapter 2 Asset Inventory and Asset Selection

A2.1. Introduction

This appendix contains both tables showing additional detail to the tables shown in Chapter 2, as well as new tables not shown at all in Chapter 2. Numbering has been kept consistent between Chapter 2 and Appendix A where possible for ease of navigation.

A2.2. Asset Inventory Development

The tables below show lists of asset types and attributes with potential types and sources of information available (Tables A2.1, A2.2, A2.3 and A2.4)

Table A2.1 Potential Transportation Asset Types and Data Sources

FHWA suggested example transportation asset categories	Transportation asset types considered for the selected sub region	Potential data type/ availability	Potential data source
Key road segments	Highways and state routes	TeleAtlas Road Network	Caltrans and MTC
Bridges and tunnels	Bridges	Reports, some GIS	Caltrans
	Tunnels and tubes	GIS	Caltrans
Signals and traffic control centers	Signals and traffic control centers	GIS	MTC, cities and Alameda County
Evacuation routes	Lifeline Routes, Emergency Routes for Oakland and other local jurisdictions	Report, some GIS	Caltrans, MTC, cities
Back-up power, communication, fueling, and other emergency operations systems	Emergency operations systems, Communication	Addresses	Caltrans, MTC
Intelligent Transportation Systems (ITS), signs	ITS	ITS Elements in GIS for State Highway	Caltrans; signs not readily available as a dataset
Port and airport assets	*Not considered as part of this pilot project; part of larger ART project*		
Transit system assets	Transit system assets (Stations, Yards)	Some in GIS	MTC-RTCI and Tiger; BART, AC Transit
Rail (passenger and freight)	Rail – passenger and freight	Maps but not in GIS	Capitol Corridor Joint Powers Authority (JPA), Union Pacific Railroad (UPRR)
Pipelines	*Not considered as part of this pilot project; part of larger ART project*		
	Bike lanes and routes	GIS	MTC has some data, developing online bike mapper for the region; ABAG, local agencies
	Designated truck routes	GIS	Caltrans has info for State Highways, local agency truck routes
	Drainage systems associated	GIS	Caltrans has storm

FHWA suggested example transportation asset categories	Transportation asset types considered for the selected sub region	Potential data type/ availability	Potential data source
	with transportation assets		drain inventory and culvert database only for State Highways, local agencies for streets and roads
	Local streets and roads (assume these include sidewalks)	GIS	MTC-Street Saver and ACTC. DPW, AFCWCD, FEMA, USACE
	Trails	Some GIS layers	Bay Trail (ABAG)

Table A2.2 Transportation Stressors/Asset Information Sought per FHWA Pilot Model

Stressor Information further defined by Transportation Sub Committee and CT	Notes on Data Availability for Streets/Roads, Highways, Bridges, Tunnels/Tubes, Transit, Rail
Age of asset	Sometimes (not as important as remaining service life)
Geographic location/Coordinates	Not readily available, but can be generated
Elevation/elevated structure	No (use Light Detection And Ranging [LIDAR])
Current/historical performance or condition (Areas that flood currently require maintenance due to weather impacts)	Yes for roads; otherwise information not readily available in database form
Level of use/service (LOS) (Passenger/ Ridership, traffic counts, forecasted demand, Average Daily Traffic (ADT) (annual average daily traffic [AADT])	Yes, in Excel format for most assets
Replacement cost	Estimates available for most assets
Repair/maintenance schedule & costs	Annual costs available for most assets
Structural design	Not readily available
Materials used/material type	Surface only for roads; not readily available
Lifetime & stage of life/remaining service life	Estimates available for most assets
Susceptibility to seismic hazard/retrofitted	Retrofit information available for most assets

Table A2.3 Transportation Importance - Evaluation and Prioritization Criteria

Criteria	Potential Data Availability
Traffic flow (annual average daily traffic [AADT] volume, transit ridership, bicycle or pedestrian use)	Bike & pedestrian counts in 150 locations in Bay Area - Excel data. (MTC) AADT and ADT for State Highways (Caltrans).
Interregional travel, such as components of the Interregional Road System (IRRS)-Focus Routes	Caltrans: These attributes are from another road network – not Teleatlas (GIS) based. Local Agencies: Information on local streets and roads.
Emergency management, potential loss of life, safety	
Adaptability (potential to reroute, length of detour, time to repair/rebuild if damaged)	
Lifeline route structure (routes deemed critical to emergency response/life saving activities that must be serviceable or detours quickly implemented following an earthquake, flood or other disruption)	
Economic costs (goods movement, disruption of economic activity, commutes, delay, etc.)	MTC is looking at a long range congestion plan. Assessments of travel times and delays may be available for this project.
Other criteria, e.g., Strategic Highway Network (STRAHNET), Surface Transportation Assistance Act (STAA) Routes, Intermodal Corridors of Economic Significance (ICE)	Caltrans has much of this information, in non-GIS format.

Table A2.4 Potential Shoreline Protection Asset Types and Data Sources

FHWA suggested example asset categories	Shoreline Asset Types considered for the selected subregion	Potential Data Type/Availability	Potential Data Source
Vegetative Cover; Wetlands; Floodplains	Non-structural shoreline protection / baylands / wetlands / vegetative cover / salt ponds	GIS-wetland and riparian base map, Bay area aquatic resource inventory, Ecoatlas, C-CAP	SFEI, DFG, SCC, East Bay Regional Park District (EBRPD), National Oceanic and Atmospheric Administration (NOAA)
	Levee (coastal and riverine)	GIS	ACFCWCD, Hayward Area Recreation and Park District (HARD), EBRPD, AECOM
	Seawalls/revetments and non-levee engineered structures		Alameda County
	Berm	GIS	ACFCD, USACE, HARD, EBRPD, AECOM
	Natural non-vegetated shorelines/beaches/ cliffs	GIS-wetland and riparian base map, Bay area aquatic resource inventory, Ecoatlas, C-CAP	SFEI, EBRPD, USGS
	Bayshore pump stations		SFEI, Alameda County (capacity, location, elevation, as-built)

INITIAL DATA RECEIVED FOR TRANSPORTATION AND SHORELINE ASSETS

The majority of data collected as part of the initial effort were GIS based. The team processed the information into several maps, portraying the data received for review and analysis. This facilitated the selection of the most relevant data for further analysis. The key data sets received, their format, and the level of detail they provide are laid out in Table A2.5 and Table A2.6.

Table A2.5 - Key data sets received

Description	Data Source
Basemap	TANA, Alameda County, SFEI
Hayward fault shaking scenario and liquefaction hazard maps	ABAG
Baylands, wetlands and hydrology mapping	SFEI, NOAA, Pacific Institute
Bayshore Pumpstations	Caltrans, Alameda County
Flood insurance data/maps; 100-year floodplain	FEMA, Alameda County
Bridges	Caltrans, Alameda County
Drainage system	Caltrans, Alameda County
Facilities for Alameda County	Caltrans
Transit stations	MTC
Emergency operation facilities	MTC
Traffic management center facilities	MTC
Roadways	TANA
Railroads	TANA
Signpost locations	TANA
Transportation analysis zones - clipped to shoreline	TANA
Bay trail	ABAG
Bike lanes	MTC
Bus routes	MTC
BART ROW along lines / stations / maintenance areas	BART
Topographic polygons and polylines / elevation data for BART structures flagged for seismic upgrades	BART
Subset of national inventory of dams	SFEI
Communities of Concern in Alameda County	MTC
2004/2005 Merrick LIDAR data for alameda coast, missing southern portion (raw .las files)	AECOM
2007 Alameda County LIDAR	Alameda County PW
2010 USGS LIDAR	USGS
2006 land cover data that inventories coastal intertidal areas, wetlands, and adjacent uplands	NOAA
Hillshade for San Francisco bay area	SFEI
Bathymetry of the bay	AECOM
Digital terrain model	AECOM

Note: for more detail on GIS data received, please refer to Table 2.7; Data Inventory

Data Inventory

The Data Inventory Matrix lists the data sets received, their format and the level of detail they provide (Table A2.6). The Data Inventory Matrix captures information about the following:

Data/Asset Type	(e.g. Base map, Shoreline, Transportation, etc.)
Status	(Received/TBD)
File Name	(e.g. wl_Water_Lines)
File Description	(e.g. Water Lines)
Source	(e.g. TANA)
Date Rcvd	Date data was received
Data Update Date	Date data was last updated or revised
Data Format	(e.g. polygon, line, point)
GIS File Type	(e.g. Geodatabase, Shapefile)
Key Attributes	(e.g. name, city name)
Scale	(e.g. CA (State); Alameda County)
Data Source Contact	Contact information of Data provider
Notes	Potential Notes for Data
Spatial Data	Yes/No
Metadata	Yes/No

A2.3 Transportation Asset Selection Methodology

FUNCTIONALITY AND OTHER CHARACTERISTICS TO SELECT REPRESENTATIVE ASSETS

Table A2.7 contains the long list of representative assets that was reviewed by the Transportation Sub-Committee, and contains their suggestions for collector and neighborhood streets. See Chapter 2 Section 2.3 in the report for an explanation of the methodology.

Table A2.7 Long List of Representative Assets

Code	Asset Category and Asset Types	Segment
A Road Network		
Interstates/Freeways: (Includes road junctions, signals, HOV ramps, drainage systems)		
T-A-01	I-80 (includes part of I-580)	Powell Street to Bay Bridge Toll Plaza (Bridge= Bridges)
T-A-02a	I-880	I-80 connection ramps
T-A-02b		7th St to I-980
T-A-02c		Oak St to 23rd Ave
T-A-02d		High St to 98th Ave
T-A-02e		Industrial Pkwy to Whipple Rd
T-A-03	SR 92	Clawiter Rd to San Mateo Bridge Toll Plaza
T-A-04	SR 61	Bay Farm Island Bridge to 98th Ave
		98th Ave to Davis St
T-A-05	SR 260 (Webster St) pt. of SR 61	All of 260 (part of 61): I-880 to Central Ave.

Principal Arterial Examples		
T-A-06	Powell St	Portion east of I-80 not in inundation area, portion west considered as unique collector below
T-A-07	West Grand Ave	I-80 to Adeline St
T-A-08	6th St	Downtown
T-A-09	7th St	At I-880; consider with highway and pump facility
T-A-10	8th St	Downtown
T-A-11	66th Ave	
T-A-12	Hegenberger Rd	San Leandro Street to Doolittle Dr
T-A-13	Airport Dr	Entire facility
T-A-14	98th Ave	Doolittle Dr to I-880
T-A-15	Harbor Bay Pkwy	
T-A-16	Industrial Blvd / Pkwy	
T-A-17	Union City Blvd	
T-A-18	Alvarado Blvd	
T-A-19	Smith St	
Collector Examples (1) Unique Collectors/ Connectors to isolated neighborhoods		
T-A-20	I-80 Frontage Rd	
T-A-21	Powell St	West of I-80
T-A-22	4th St	
T-A-23	Dennison St	
T-A-24	Embarcadero	
Collector Examples (2) Determined through selection of Focus Area - "maze" and Oakland Waterfront		
	Mandela Pkwy	West Grand to I-580
	Maritime St	
	Ron Cowan Pkwy	Entire facility
	Swan Way	
Neighborhood Streets: Determined through selection of Focus Area - "maze" and Oakland Waterfront		
	Wood St	
	Beach St	
	Burma Rd	Entire facility
	Tulagi St	
	3rd St	Mandela Pkwy to Market St
	6th Ave	
	10th Ave	
	Tidewater Ave	
	Coliseum Way	
	Earhart Rd	
T-A-25	Cabot Rd	

Tunnels and Tubes		
T-A-26	Posey Tube (SR 260) - Connects Alameda with East Bay	All, including approach ramps
T-A-27	Webster St Tube (SR 61) - Connects Alameda with East Bay	All, including approach ramps
Toll, Interstate and State Bridges of high importance		
T-A-28	Bay Bridge (I-80)	from Toll Plaza until Alameda County boundary
T-A-29	San Mateo Bridge (SR 92)	from Toll Plaza until Alameda County boundary
Alameda Bridges		
T-A-30	Fruitvale Bridge	
T-A-31	Park Street Bridge	
T-A-32	Bay Farm Island Bridge	entire facility, including adjacent bicycle bridge
Local Bridges		
	Local bridges and overpasses will be included in the analysis of the selected roadway segments above.	

SHORT LIST OF ASSETS FOR VULNERABILITY ASSESSMENT

Table A2.8 contains the short list of assets for which detailed sensitivity or stressor information was finally collected. See Chapter 2 Section 2.3 in the report for an explanation of the methodology.

Table A2.8: Short list of assets selected for final data collection exercise on stressor information

A Road Network

Code	Asset Category and Asset Types	Segments chosen
Interstates/Freeways and State Routes		
T-A-01	I-80 (includes part of I-580)	Powell Street to Bay Bridge Toll Plaza
T-A-02a	I-880	I-80 connection ramps
T-A-02b		7th St to I-980
T-A-02c		Oak St to 23rd Ave
T-A-02d		High St to 98th Ave
T-A-03	SR 92	Clawiter Rd to San Mateo Bridge Toll Plaza
T-A-04	SR 61	Bay Farm Island Bridge to 98th Ave
Principal Arterials		
T-A-07	West Grand Ave	I-80 to Adeline St
T-A-12	Hegenberger Rd	San Leandro Street to Doolittle Dr
T-A-13	Airport Dr	Entire facility
T-A-20	I-80 Frontage Rd	Entire facility

Code	Asset Category and Asset Types	Segments chosen
Collector and Neighborhood Streets		
T-A-21	Powell St (City of Emeryville)	West of I-80
	Mandela Pkwy	West Grand to I-580
	Ron Cowan Pkwy	Entire facility
	Burma Rd	Entire facility
	3rd St	Mandela Pkwy to Market St
T-A-25	Cabot Blvd	Entire facility
Tunnels and Tubes		
T-A-26	Posey Tube (SR 61 / 260)	All, including approach ramps
T-A-27	Webster St Tube (SR 61 / 260)	All, including approach ramps
Bridges		
T-A-28	Bay Bridge (I-80)	From Toll Plaza until Alameda County boundary
T-A-29	San Mateo Bridge (SR 92)	From Toll Plaza until Alameda County boundary
T-A-31	Park Street Bridge	Entire facility
T-A-32	Bay Farm Island Bridge	Entire facility, including adjacent bicycle bridge

B Transit Assets

Code	Asset Category and Asset Types	Segments chosen
BART Rail Alignment - including support facilities (traction power substations, ventilation, etc.)		
T-B-17	BART Line: east approach of Oakland Wye	Tunnel portal only
T-B-18	BART Transbay Tube	Entire facility
T-B-20	BART Line: between Transbay Tube and Oakland Wye	Elevated structure between I-880 overcrossing and I-880 undercrossing
T-B-XX	Future Oakland Airport BART Connector	Route serving/crossing SLR exposure area
Rail stations		
T-B-22	Lake Merritt BART Station	Entire facility
T-B-23	West Oakland BART Station	Entire facility
T-B-24	Coliseum / Oakland Airport BART Station	Entire facility
T-B-26	Oakland Jack London Square Amtrak Station	Entire facility
Rail – passenger and freight (Capitol Corridor)		
T-B-28	UP Martinez Subdivision	10th Street Crossover to 34th Street Crossover
T-B-29	UP Niles Subdivision	Magnolia Crossover to East Oakland Yard
T-B-30	UP Niles Subdivision	66th Avenue Crossover to Coliseum Crossover
T-B-32	Jack London Square Ferry Terminal	Entire facility
T-B-33	Alameda Gateway Center Ferry Terminal	Entire facility

C Facilities

Code	Asset Category and Asset Types
Traffic Management Centers (includes signal and traffic control centers)	
T-C-01	City of Alameda TMC
Bus Service Facilities (Includes Bus Yards and Depots)	
T-C-05	AC Transit Maintenance (1100 Seminary)
Rail – Passenger and Freight (Capitol Corridor) Yards and Depots	
T-C-08	BNSF Intl Gateway Intermodal Yd
T-C-09	Capitol Corridor Norcal O&M Yard
T-C-10	7th Street Highway and Railroad Pumps

D Bicycle and Pedestrian Facilities

Code	Asset Category and Asset Types
Bike and Pedestrian Routes/Trails	
T-D-01	Lake Merritt Connector Trail
Class I portions of Bay Trail (existing and proposed), potential segments	
	Oakland - Jack London Square Ferry to Estuary Park
	Oakland - Embarcadero Cove to Union Point Park
	Oakland - East Creek Point to Swan Way/Airport Channel
	Alameda - Ferry Connector
	Hayward - along Hayward Regional Shoreline)
T-D-02	Hayward / Union City - Alameda Creek Regional Trail

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Appendix B - Accompanying Chapter 4 Climate Science and Climate Impacts

B4.1 Introduction

This appendix accompanies Chapter 4 and provides the detailed historic and projected climate science data, including the assumptions and data limitations associated with the current state of the science, and describes the data used in the subregional scale evaluation of sea level rise (SLR) and the resultant inundation maps. This appendix also presents the detailed methodologies for the development of the inundation maps, and the methodology used to assess the potential for overtopping along the shoreline assets in the Alameda County pilot study region.

B4.2 Climate Science Data Sources

Sources presenting historical, current, and projected data were reviewed as part of the climate information gathering component of this pilot study. These sources are summarized here and referenced as appropriate throughout the chapter.

B4.2.1 HISTORICAL DATA

- California Climate Change Center (Heberger et al. 2009)
- California Natural Resources Agency (2009)
- California Ocean Protection Council (CO-CAT 2010)
- Environment California, Research & Policy Center (Madsen and Figdor 2007)
- Intergovernmental Panel on Climate Change (IPCC), Working Group IV (IPCC 2007a)
- National Oceanic and Atmospheric Administration (NOAA)
    - Coastal Services Center (NOAA 2011a)
    - Tides and Currents (NOAA 2011b)
    - National Weather Service, Climate Prediction Center (NOAA 2011c)
    - Department of Commerce (NOAA 2011d)
    - National Climatic Data Center (NOAA 2011e)
- U.S. Geological Survey (USGS) (USGS 1999, 2000)

B4.2.2 PROJECTED DATA

- California Climate Change Center (Cayan et al. 2009; Knowles 2009)
- California Energy Commission (Mastrandrea et al. 2009)
- California Natural Resources Agency (2009)
- California Ocean Protection Council (CO-CAT 2010)
- IPCC Working Group III (IPCC 2000)
- IPCC Working Group I, Fourth Assessment (IPCC 2007b, 2007c, 2007d)
- National Aeronautics and Space Administration (NASA 2009)
- NOAA, Coastal Services Center (NOAA 2008)
- Proceedings of the National Academy of Sciences (Raupach et al. 2007; Vermeer and Rahmstorf 2009)
- San Francisco Bay Conservation and Development Commission (BCDC 2009)

Other technical articles were also reviewed and are referenced as appropriate.

B4.2.3 UNCERTAINTIES ASSOCIATED WITH CLIMATE CHANGE PROJECTIONS

Each climate dataset has associated uncertainties that are identified so that they can be considered within the overall evaluation. Uncertainties associated with observational data are generally smaller than with projections of future climate conditions. The range of uncertainty associated with future climate projections is much larger due to the large number of sources of uncertainty which include the following:

(1) uncertainties with physical processes and their representation in global and regional climate models;
(2) uncertainties with future greenhouse gas emissions; and
(3) the stochastic and unpredictable aspects of the climate system.

The purpose in estimating the degree of uncertainty associated with climate datasets is to consider how likely actual future conditions will match climate predictions. A larger range of uncertainty translates to a smaller likelihood that the mean of the projected range will be representative of the actual future value.

B4.3 Relevant Climate Information (Summary of available information, Underlying Assumptions, Data Gaps and Range of Uncertainties)

Sources presenting historical, current, and projected data were reviewed to summarize local- and regional-level climate information for use in assessing the vulnerability of transportation infrastructure to climate change effects (FHWA 2010). Each climate dataset has associated uncertainties that are identified so that they can be considered as part of the overall evaluation.

B4.3.1HISTORICAL DATA

Historical data include observational climate-monitoring data, climate maps, and other state or local weather and climate data. Of particular interest with respect to the evaluation of the project area are historical observations of SLR, tidal range, and storm frequency and intensity.

B4.3.1.1 SEA LEVEL RISE

Sea level began rising globally at the end of the last glaciation more than 10,000 years ago (USGS 2000). Data on ocean water levels are collected from a worldwide network of more than 1,750 tidal gages continuously, and new satellite-based sensors are extending these measurements. The data indicate that the global mean sea level is rising at an increasing rate and SLR is already affecting much of California's coastal region, including the San Francisco Bay and its upper estuary (the Delta). Water level measurements from the San Francisco Presidio gage (CA Station ID: 9414290), shown in Figure B4.1, indicate that mean sea level rose by an average of 0.08 ± 0.008 inch per year (reported as 0.2 ± 0.02 centimeter per year) from 1897 to 2006, equivalent to a change of 8 inches (20 centimeters) in the last century (Heberger et al. 2009).

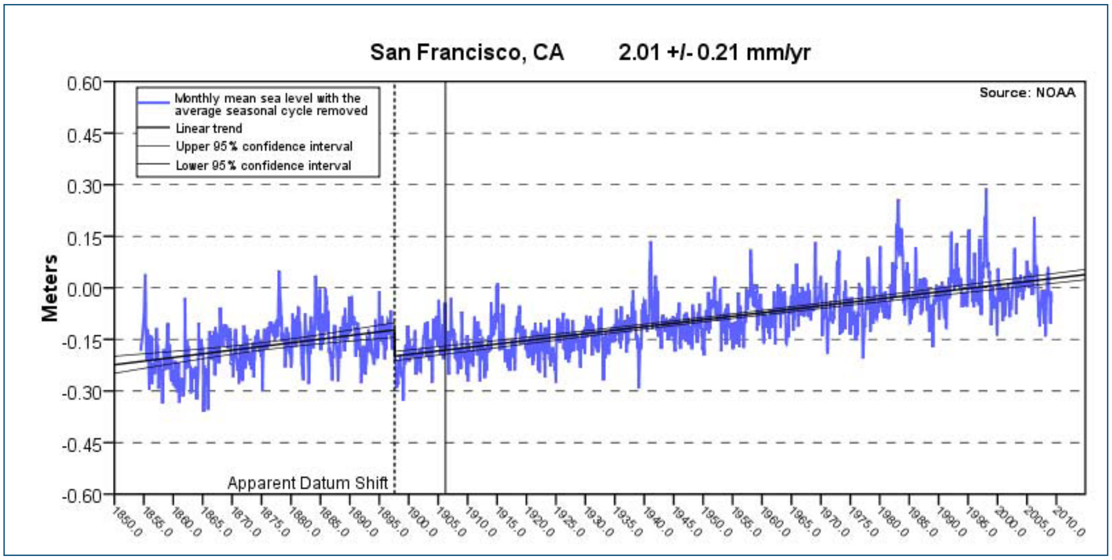

Figure B4.1. Monthly Mean Sea Level at the San Francisco Tide Station: 1854–2006

Source: NOAA 2011

Note: The solid vertical line shows the earthquake of 1906. NOAA researchers fit separate trend lines before and after an apparent datum shift (vertical movement of the land surface) that occurred in 1897 with the relocation of the tide gage from Marin County to its current location in the Presidio area of San Francisco, disrupting consistent measurements.

According to the State of California Ocean Protection Council Science Advisory Team, future SLR projections should not be based on linear extrapolation of historic sea level observations. For estimates beyond one or two decades, linear extrapolation of SLR based on historic observations is considered inadequate and would likely underestimate the actual SLR because of expected nonlinear increases in global temperature and the unpredictability of complex natural systems (CO-CAT 2010).

B4.3.1.2 TIDAL RANGE

Tides can be described in terms of very long waves driven by the gravitational pull of astronomical bodies such as the sun, moon, and planets. The tidal currents entering through the Golden Gate interact with the complex San Francisco Bay bathymetry to drive the bay's complex hydrodynamics. The tides in San Francisco Bay are mixed semidiurnal, with two high and two low tides of unequal heights each day. In addition, the tides exhibit strong spring-neap variability, with the spring tides (larger average tidal range) occurring approximately every 2 weeks during the full and new moon. Spring tides exhibit the greatest difference between successive high and low tides. Neap tides (smaller average tidal range) occur approximately every 2 weeks during the moon's quarters, and exhibit the smallest difference between successive high and low tides.

The tides in southern San Francisco Bay are also amplified due to a mix of progressive and standing wave behavior, where waves are reflected back upon themselves (Walters et al. 1985). The mean tide range increases from approximately 4.2 feet (1.3 meters) at the Presidio (Station 9414290), to over 4.8 feet (1.46 meters) near the Oakland International Airport in Alameda County (Station 9414750), to approximately 6.4 feet (1.95 meters) south of the San Mateo Bridge in Redwood City (Station 9414523). These values were calculated based on NOAA's published tidal datums at the respective tide stations. SLR has the potential to exacerbate these differences, such as increasing the tide range or amplifying the amount of SLR. For this reason, a thorough understanding of San Francisco Bay hydrodynamics is necessary to fully appreciate the potential impacts of climate change and SLR, although the level of effort required for this analysis is beyond the scope of this study.

B4.3.1.3 STORM FREQUENCY AND INTENSITY

Scientists predict that global warming will increase the frequency of major storms with heavy rainfall or snowfall, and that the amount of precipitation falling as rain rather than snow will increase. Historical records of rainfall across the United States were evaluated by Environment California, Research & Policy Center (Madsen and Figdor 2007) and the results indicate that extreme precipitation has become more frequent over the last 60 years across most of America. Figure B4.2 provides a summary of average annual frequency of storms with extreme precipitation from 1948 to 2006 and illustrates the increasing trend of extreme storm events over time.

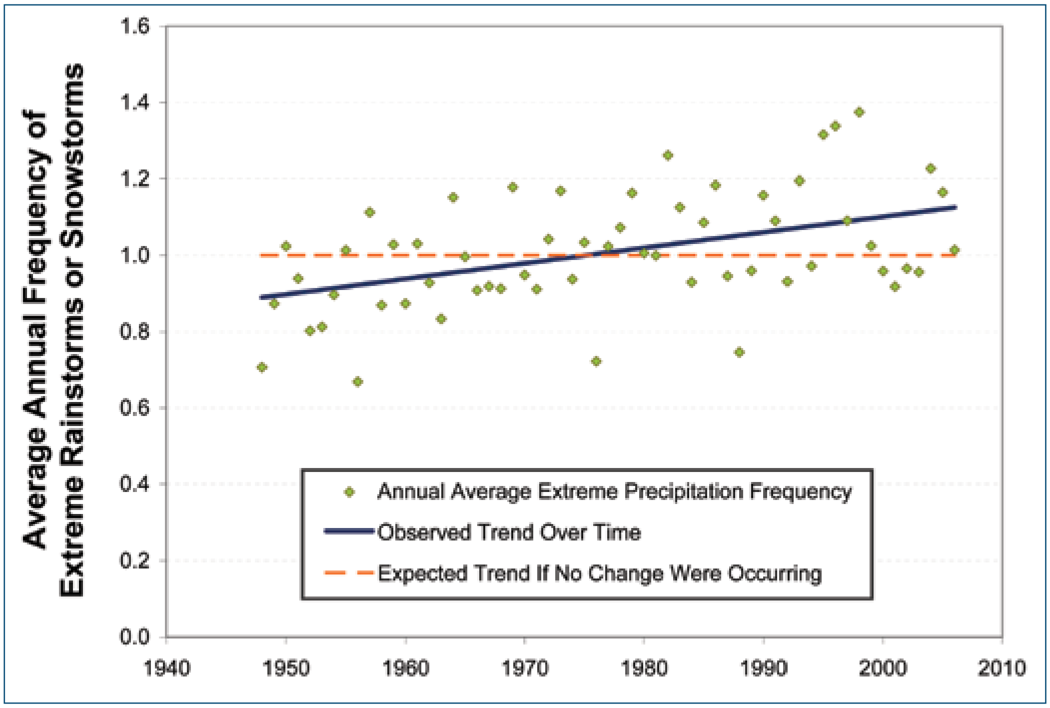

Figure B4.2. Annual Average Frequency of Storms with Extreme Precipitation in the United States, 1948–2006

Source: Madsen and Figdor 2007

The study included an evaluation of the nine regions of the contiguous United States. California is located within the Pacific region. There were multiple years with exceptionally frequent extreme rainfall events and snowstorms in five of the nine regions, one of which was the Pacific region. In the Pacific region, extreme precipitation frequency was more than 50 percent greater than the long-term average (as measured between 1948 and 2006) in 1955, 1969, 1980, 1982, 1983, 1995, 1996, and 1998.

A number of these extreme precipitation events are associated with El Niño/La Niña events (NOAA 2011c). El Niño is characterized by unusually warm temperatures and La Niña by unusually cool temperatures in the equatorial Pacific (NOAA 2011d). El Niño (and La Niña) is a natural but largely unpredictable condition that results from complex interplay among clouds and storms, regional winds, oceanic temperatures, and ocean currents along the equatorial Pacific (USGS 2000). El Niño events have been present for thousands and possibly millions of years, however it has been hypothesized that warmer global sea surface temperatures can enhance the El Niño phenomenon (NOAA 2011e). Historical records indicate that El Niños have been more frequent and intense in recent decades (NOAA 2011e).

During the 1997 to 1998 El Niño event, wind-driven waves and abnormally high sea levels contributed to hundreds of millions of dollars in flood and storm damage in the San Francisco Bay region (USGS 1999). Analyses by the USGS of nearly 100 years of sea-level records collected near the Golden Gate Bridge found that these abnormally high sea levels were the direct result of that year's El Niño atmospheric phenomenon (USGS 1999). These high sea levels were the result of long, low Kelvin waves generated in the western Pacific Ocean as part of an El Niño event. As these waves move along the west coast, they pass the mouth of San Francisco Bay; the higher sea level outside the bay generated by the waves causes more ocean water to flow into the bay, raising sea levels inside the bay as well (USGS 1999).

B4.3.1.4 WAVE CLIMATE

With increasing storm intensity, the potential exists for storm-generated waves to increase in height resulting in an overall change in wave climate. Wave climate describes the long-term statistical characterization of the behavior of waves and is influenced by the strength of the wind and the length of water over which the wind has blown (referred to as "fetch"), and storm duration. The ocean wave climate, and especially the occurrence of high wave energy levels generated by severe storms, is important to the operation and safety of shipping, and to the occurrence of erosion in the coastal zone (Allan and Komar 2000). An evaluation of wave climate was conducted by Allan and Komar (2000) along the North Pacific coast, extending from the Gulf of Alaska to Southern California. The results demonstrate that the heights of storm-generated waves have increased during the past three decades with the greatest changes having occurred in the Pacific Northwest in Washington and Oregon, with slightly smaller increases observed in northern California. These results reflect the growing intensities of storms that cross the Pacific Northwest and Northern California during the winter and are of concern since the risks from coastal erosion and inundation also increase (Allan and Komar 2000).

The wave climate in the San Francisco Bay is driven predominantly by tidally forced and wind-forced flows and their interaction with bay bathymetry. Tides in the San Francisco Bay are described in Section B4.3.1.2. Tidally forced flows in the South Bay are driven by the volume of water between mean low water and mean high water, or the "tidal prism," in combination with bathymetry, which determines the patterns and speed of tidal currents and subsequent sediment transport. Wind-generated waves also drive flow in the San Francisco Bay. Typically, winds drive a surface flow which then induces a return flow in the deeper channels (Walters et al. 1985). Onshore breezes during the spring and summer generate significant wind-forced flows in the bay.

Ocean swell propagating through the Golden Gate also has an effect on the wave energy in the bay, particularly during periods when tidal forcing is limited and wind waves are small (Talke and Stacey 2003). For example, the tsunami generated from the massive earthquake in Japan generated a slow-moving but visible swell in the calmer waters of the San Francisco Bay (Rosoff 2011). The tsunami wave entered through the Golden Gate during a time of low tide, which meant that wave energy dissipated quickly from the shallow water of the bay. Under a future condition with deeper water in the bay, the wave energy would not dissipate as quickly. Tsunamis are geologic events that are infrequent and unpredictable. More typical ocean swell effects are likely to occur from storm-generated waves.

B4.3.2 PROJECTED DATA

Global and regional climate models can be used to project the range of estimated SLR rates based on emission scenarios and climate simulations. Global climate models are based on well-established physical principles and have been demonstrated to reproduce observed features of recent climate and past climate changes (IPCC 2007b). They are used to investigate the processes responsible for maintaining the general circulation and its natural forced variability to assess the role of various forcing factors in observed climate change, and to provide projections of the response of the system to scenarios of future external forcing (IPCC 2007c). There are various global climate models ranging from Atmosphere-Ocean General Circulation Models (AOGCMs) and Earth System Models of Intermediate Complexity to Simple Climate Models. There is considerable confidence that AOGCMs provide credible quantitative estimates of future climate change, particularly at continental and larger scales (IPCC 2007b).

Global models provide information about climate response to various scenarios, but usually at a low resolution that does not provide the level of detail needed to make planning decisions at a local level. For example, the AOGCMs cannot provide information at scales finer than their computational grid, which is typically on the order of 124 miles (200 kilometers) (IPCC 2007c). A region-based model can be developed to provide an evaluation of climate processes that are unresolved at the global model scale. There is a broad range of region-based climate models from the subcontinental scale with a resolution of approximately 31 miles (50 kilometers) to a local scale with resolution of approximately (0.6 to 3 miles) (1–5 kilometers) (IPCC 2007c). The resolution is typically determined based on the size of the study area and by climate-relevant features such as topography and land cover, and specific processes to be evaluated such as runoff, infiltration, evaporation, and extreme events such as precipitation (IPCC 2007c).

AOGCMs remain the primary source of regional information on the range of possible future climates (IPCC 2007b). Downscaling of AOGCM simulations is commonly used to take information from the global climate models to develop region-based climate models. Downscaling is a process by which the results from a global climate model are used to create the boundary conditions of a finer resolution regional model. As a result, many region-based climate models that provide locally relevant climate information are based on model output from global models. Coupling models in this way implies that uncertainties cascade through the ensemble modeling results and are thus somewhat additive.

B4.3.2.1 GLOBAL PROJECTIONS

In order to evaluate climate change effects such as SLR, the IPCC developed future emission scenarios (IPCC 2000) that differ based on varying assumptions about economic development, population, regulation, and technology. In order to examine a lower and an upper end of future emissions, as well as a business as usual case (which is most closely described by the IPCC scenario A2), three of IPCC's emission scenarios were chosen to develop SLR projections, which the IPCC published in its AR4 Report in 2007 (IPCC 2007d):

A2 - High-Emissions Scenario

The A2 future scenario represents a competitive world lacking cooperative development. It portrays a future in which economic growth is uneven, leading to a growing income gap between developed and developing nations. Under this scenario, world population exceeds 10 billion by 2050. Atmospheric carbon dioxide (CO_2) concentrations at the middle and end of the 21st century in this scenario would be about 575 and 870 parts per million (ppm), respectively, which exceeds concentrations associated with dangerous climate change (at ~350 to 400 ppm).

B1 - Low-Emissions Scenario

The B1 future scenario reflects a high level of environmental and social consciousness combined with global cooperative and sustainable development and high economic growth. Global population would peak by mid-century, then decline. The low-emission scenario also includes a shift to less fossil fuel-intensive industries and increased use of clean and resource-efficient technologies. Atmospheric CO_2 concentrations would reach 550 ppm by 2100, below catastrophic levels, but about double pre-industrial levels (~280 ppm).

A1FI - Fast-Paced High-Emissions Scenario

The A1FI future scenario describes a world characterized by rapid economic growth. Global population would peak at mid-century and decline thereafter. New and more efficient technologies would be rapidly introduced. However, fossil fuels would remain the primary energy supply, with coal, oil, and gas use dominating for the foreseeable future. Atmospheric carbon dioxide concentrations would reach 940 ppm by 2100—more than triple pre-industrial levels, and more than double the level associated with dangerous climate change.

Since the IPCC released these scenarios, the world has followed a business-as-usual emissions path, which most closely resembles the A2 High-Emissions Scenario (Raupach et al. 2007).

As noted by the IPCC (2007b), climate models are derived from fundamental physical laws which are then subjected to physical approximations appropriate for the large-scale climate system, and then further approximated through mathematical discretization. Computational constraints restrict the resolution that is possible in the discretized equations, and some representation of the large-scale impacts of unresolved processes is required. Evaluations of global climate models show that predictions of mean climate features, such as the large-scale distributions of atmospheric temperature, precipitation, radiation and wind, and of oceanic temperatures, currents, and sea ice cover, are being represented with increasing skill over the past decade; however, numerous issues remain (IPCC 2007b).

Uncertainties in predictions of anthropogenic climate change arise at all stages of the modeling process by errors in the representation of Earth system processes and by internal climate variability (IPCC 2007d). These errors are partially overcome through evaluations of an ensemble of global climate models that sample different representative aspects of Earth processes, but even this approach has limitations due to the fact that some processes may be missing from the set of available models and alternative representations of other processes may share common systematic biases (IPCC 2007d). For example, future radiative forcing are yet to be accounted for in the ensemble projections, including those from land use change, variations in solar and volcanic activity, and methane release from permafrost or ocean hydrates (IPCC 2007d).

B4.3.2.1.1 SLR Projections

Based on these scenarios, global mean sea level was projected to rise by 0.7 foot to 2 feet (0.2 meter to 0.6 meter) by 2100, relative to a 1980 to 2000 baseline in IPCC's AR4 Report (IPCC 2007d). However, projected rise in sea level obtained from global climate models evaluated during the IPCC's AR4 Report were subsequently found to under predict observed SLR by approximately 50 percent for the periods 1990 to 2006 and 1961 to 2003 (Vermeer and Rahmstorf 2009). This error is attributed to the limited ability of global climate models to simulate the dynamics of ice sheets and glaciers and to a lesser extent, the inability to simulate oceanic heat uptake, which is not sufficiently understood (Vermeer and Rahmstorf 2009). However, global climate models do predict global mean temperature with confidence (as compared to historical records) and projections of SLR may be projected using semiempirical approaches based on projected global mean temperature to improving estimates of SLR. Rahmstorf first determined the historic trend in the relationship and then projected that trend into the future using the IPCC's projected temperature increases associated with the Special Report on Emissions Scenarios: 2.5 degrees Fahrenheit (°F) (1.4 degrees Celsius [°C]) for the lowest emissions scenario to 10.4°F (5.8°C) for the highest emissions scenario (Rahmstorf 2007). The temperature trend relationship was revised in 2009 to include the relationship between components of sea level that adjust quickly to temperature change, for example, the heat content of the oceanic surface mixed layer.

Rahmstorf's method indicates that SLR from 1993 to 2010 has outpaced IPCC projections (Vermeer and Rahmstorf 2009). Estimates of SLR by 2100 range from 10 inches (50 centimeters) to 55 inches (140 centimeters), respectively (BCDC 2009). Since 2007, projections have increased slightly, particularly for the B1 scenario (see Table B4.1 and Figure B4.3). The A1FI scenario projects a SLR of up to almost 6 feet (nearly 1.8 meters) by 2100.

Table B4.1. Temperature Ranges and Associated Sea Level Ranges by 2100 for Different IPCC Emission Scenarios

Scenario	Temperature range, °C above 1980–2000	Model average, °C above 1980–2000	Sea level range, cm above 1990	Model average, cm above 1990
B1	1.4–2.9	2.0	81–131	104
A2	2.9–5.3	3.9	98–155	124
A1FI	3.4–6.1	4.6	113–179	143

Source: Vermeer and Rahmstorf 2009.

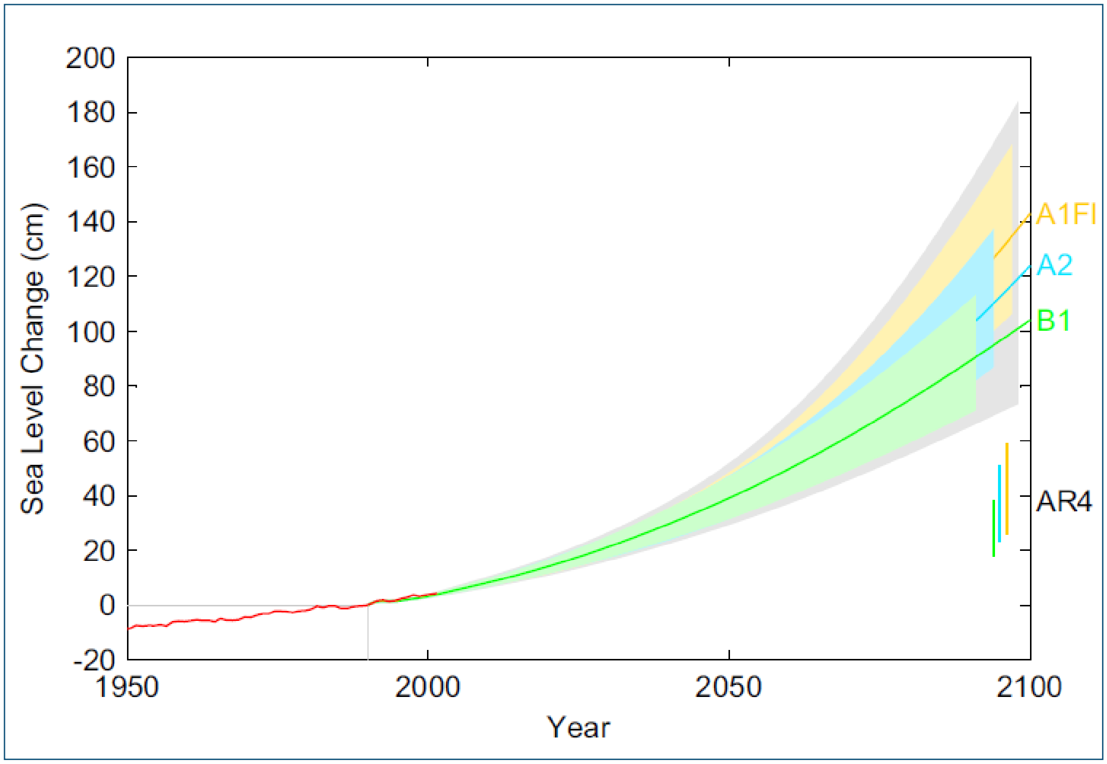

Figure B4.3. Projected SLR: 1990–2100

Note: Based on IPCC (2007c) temperature projections for three different emission scenarios. The sea level range projected in the IPCC AR4 for these scenarios is also shown for comparison in the bars on the bottom right. Observation-based annual global sea level data (Church and White 2006) are shown in red.

Table B4.2 provides an overview of SLR projections under high emission scenarios by 2100 from various sources. The highest estimates consider continued melting of the West Antarctic and Greenland ice sheets.

Table B4.2. SLR Projections: 2100

Source	Meter SLR by 2100	Inches	Feet
IPCC (2007)	**Up to 79 cm**	**31**	**2.6**
Rahmstorf (2007)	**1.4 m**	**55**	**4.5**
Rahmstorf and Vermeer (2009)	**1.8 m**	**70**	**5.8**
Hansen (2007)	**5 m**	**197**	**16**

B4.3.2.1.2 Catastrophic SLR

West Antarctica is particularly vulnerable to climate changes because its ice sheet is grounded below sea level and surrounded by floating ice shelves, making it more susceptible to warming ocean waters. If the West Antarctic ice sheet completely melted, global sea level would rise by 16–20 feet (5–6 meters) (NASA 2009). In addition, Greenland's ice sheets could add another 20 feet (6 meters) (USGS 2000). Neither ice sheet is anticipated to melt completely by 2100; however, they will continue to melt after temperatures stabilize, which will likely take a few millennia.

Regardless of the time scale involved, an analogy to the previous interglacial period suggests that a few degrees Celsius of sustained warming can cause enough melting to raise sea level 20 feet (4–6 meters) before the ice sheets reach equilibrium (Overpeck et al. 2006).

Perhaps the most notable finding from the IPCC is that the effects of GHG emissions will continue long after emissions are reduced. The IPCC projects that temperature increases would continue for a few centuries before temperatures stabilize. SLR from thermal expansion and ice-sheet melting would continue for centuries to millennia (IPCC 2007d). However, as shown in Figure B4.3 above, higher emissions translate into higher temperatures and faster melting. It is probable that this level of warming may be achieved or even exceeded by 2100 in the absence of intervention, though it would likely take far longer to realize the full sea level change of 20 feet (6 meters) from melted land ice.

As noted above, estimates of SLR by 2100 range from 10 inches (50 centimeters) to 55 inches (140 centimeters) (BCDC 2009). The estimate of 55 inches (140 centimeters) by 2100 is now widely used by the State of California for planning purposes. California’s interim guidance for incorporating SLR projections into planning and decision making directs state agencies to “use the ranges of SLR presented in the December 2009 *Proceedings of National Academy of Sciences* publication by Vermeer and Rahmstorf as a starting place and select SLR values based on agency and context-specific considerations of risk tolerance and adaptive capacity (CO-CAT 2010).”

Table B4.3 provides an overview of the SLR projections provided in the interim guidance document. The California Ocean Protection Council used Vermeer and Rahmstorf’s 2009 projections, but adjusted them to a 2000 baseline to reflect the SLR of about 1.3 inches (3.4 centimeters) that had already occurred between 1990 and 2000 by subtracting them from the projected ranges.

These estimates are based on model simulations and are not considered “predictions,” but rather are possible scenarios of plausible climate impacts that might affect California in the next century. These projections do not account for catastrophic ice melting, so they may underestimate actual SLR. The SLR projections included in this table do not include a safety factor to ensure against underestimating future SLR. For dates after 2050, three different values for SLR are shown based on low, medium, and high future greenhouse gas emission scenarios. These values are based on the Intergovernmental Panel on Climate Change emission scenarios as follows: B1 for the low projections, A2 for the medium projections and A1FI for the high projections.

Table B4.3. SLR Projections Using 2000 as the Baseline

Year	Emissions Scenario	Range of Models, inches (cm) above 2000*	Average of Models, inches (cm) above 2000*
2030		5-8 in (13-21 cm)	7 in
2050		10-17 in (26-43 cm)	14 in (36 cm)
2070	Low (B1)	17-27 in (43-70 cm)	23 in (59 cm)
	Medium (A2)	18-29 in (46-74 cm)	24 in (62 cm)
	High (A1FI)	20-32 in (51-81 cm)	27 in (69 cm)
2100	Low (B1)	31-50 in (78-128 cm)	40 in (101 cm)
	Medium (A2)	37-60 in (95-152 cm)	47 in (121 cm)
	High (A1FI)	43-69 in (110-176 cm)	55 in (140 cm)

Source: CO-CAT 2010

*Note: Vermeer and Rahmstorf's paper presents values using 1990 as a baseline. Here the values are adjusted by subtracting 1.3 inches/3.4 centimeters, which represents 10 years of SLR that has already occurred, at an average rate of 0.1 I nch/3.4 millimeter per year.

B4.3.2.2 REGIONAL PROJECTIONS

B4.3.2.2.1 Assessment of California Climate Change Scenarios

An assessment of climate change scenarios and SLR estimates was conducted for California (Cayan et al. 2009) to provide a comprehensive view of model results from several sources using two downscaling methods. Six global climate models were selected for the analysis using the A2 and B1 IPCC emission scenarios to assess climate changes and their impacts on California. Two downscaling methods were employed for the assessment (one referred to as constructed analogues and the second is referred to as bias correction and spatial downscaling), both of which performed reasonably well but did result in noteworthy differences indicating that downscaling techniques should be selected based on the intended use of the output data. The most appropriate downscaling technique depends on the variables, seasons, and regions of interest, on the availability of daily data; and whether the day-to-day correspondence of weather from the global climate model needs to be reproduced for some applications (Cayan et al. 2009).

The results of the analysis confirmed the results of many previous studies – rising temperatures and rising sea levels are found in all of the projections. The simulations do have variability in the projection of these changes over time, but in general, the tendency is that these two variables rise quite steadily and rather linearly over the 21st century. As would be expected, the higher A2 GHG scenario results in higher warming projections and greater rates of SLR over the same model period. As a result of increasing temperature and SLR, wave runup along California beaches is predicted to increase and there is a predicted loss in spring snowpack in the Sierra Nevada. Figure B4.5 illustrates the projected changes in wave runup in the San Francisco area for the A2 and B1 scenarios. As temperatures rise, there is a substantial increase in the occurrence, magnitude, and duration of certain kinds of extremes, such as heat waves and high sea level events (Cayan et al. 2009). Other results from the simulations indicated that the warming trends are more intense in the summer projections than winter, and there is increased warming in the interior relative to the coast. Additionally, there is some indication from a subset of the various model results that the 21st century will become significantly drier (particularly in central and southern California) as a result of a rise in sea level pressure in the key storm track and wind wave and precipitation generating regions across the North Pacific and along Northern California and Oregon's Pacific coast. The drying changes that are projected rival or exceed the largest observed multidecadal deficits within the modern California historical experience. Along with the consistent decline in precipitation described above, a subset of the various model results project that the incidence of coastal storms and the level of wind wave energy reaching much of the California coast decreases, at least marginally, over the 21st century.

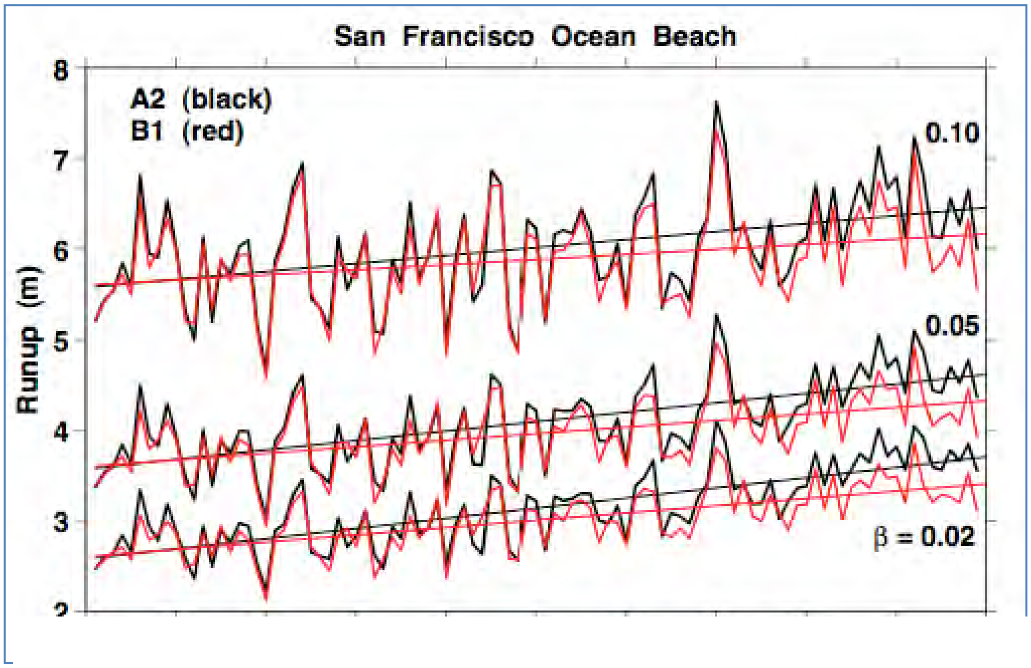

Figure B4.5. Projected Mean Winter (November through March) Runup, San Francisco Ocean Beach

Source: Cayan et al. 2009
Note: 98th percentile wave height amplitudes for both low, B1 (red) and high, A2 (black) GHG emission scenario se level projections.

B4.3.2.2.2 San Francisco Bay Regional Model/SLR Assessment

The potential inundation due to rising sea levels in the San Francisco Bay region was assessed using the highest resolution elevation data available combined with the results of a hydrodynamic model of the San Francisco Estuary (Knowles 2009). The highest resolution elevation data available at the time of this evaluation were compiled from five sources; four of the five sources had a vertical uncertainty of 4–16 inches (10–40 centimeters), and one of the sources had a vertical uncertainty of 39 inches (100 centimeters). All the datasets were resampled to a common horizontal resolution of 7 feet (2 meters) and then merged into one dataset. Other datasets were used to obtain regional elevation data to delineate open water areas along the shorelines.

The hydrodynamic model was driven by a projection of hourly water levels at the Presidio as projected from a combination of climate model outputs and empirical models that incorporate astronomical storm surge, El Niño, and long-term SLR influences. The hydrodynamic model chosen for the analysis was TRIM-2D because this model has been shown to accurately reproduce the historical amplitudes and phases of tidal constituent through the San Francisco Bay and is capable of performing the century-long simulation needed to address the effects of long-term climate change in a reasonable amount of time (Knowles 2009). TRIM-2D is a two-dimensional hydrodynamic model for simulating inland water flows governed by tidal, wind and riverine inputs (such as the San Francisco Bay Estuary). The TRIM-2D model was calibrated using the 100-year projection of mean sea level at the Presidio that was produced by Cayan et al (2009) using the method of Rahmstorf (2007), based on global mean temperatures as projected by the CCSM3 global climate model under the A2 greenhouse gas emissions scenario. The CCSM3 global climate model was one of the six global climate models included in the assessment of California climate change scenarios and was shown to simulate winds that generate waves that compare reasonably well statistically with coincident observations from buoys along the coast (Cayan et al. 2009). Figure B4.6 illustrates the conversion of global mean air temperatures derived from the global climate models and the corresponding relative SLR as estimated using the Rahmstorf model.

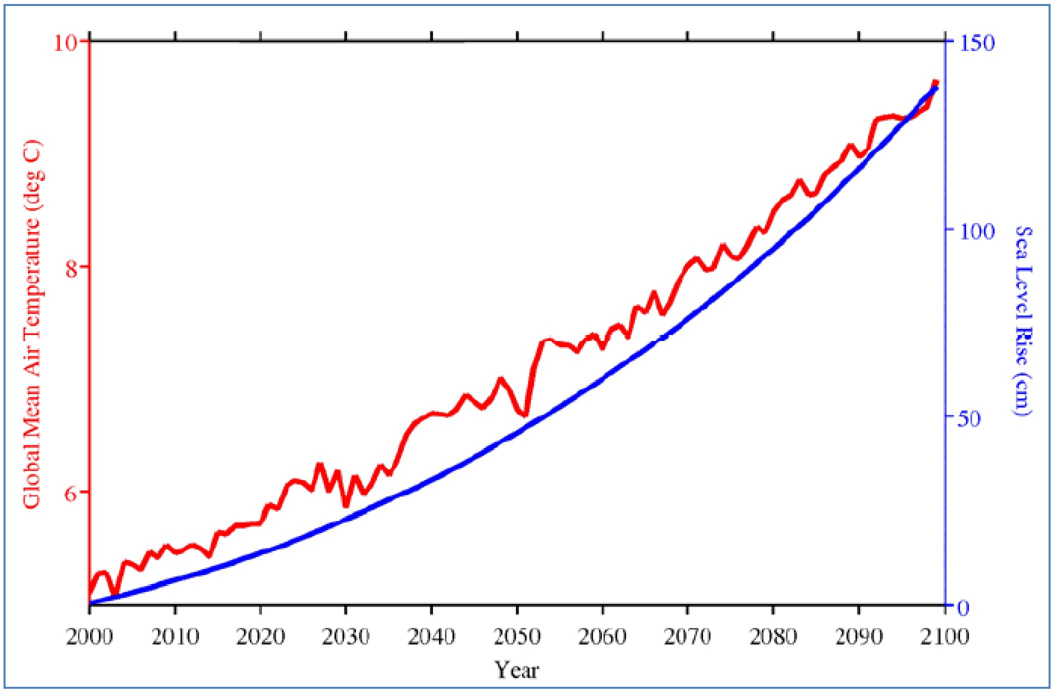

Figure B4.6. Projected Global Mean Surface Air Temperatures (red) from the CCSM3-A2 Global Climate Model and Corresponding Relative Sea Level Rise (blue) from the Rahmstorf model.

Source: Knowles 2009

Using the Rahmstorf method, this warming corresponds to a 16-inch (40-centimeter) rise in sea level by midcentury and a 55-inch (139-centimeter) rise in mean sea level by 2100.

Figure B4.7 illustrates the areas where elevations lie below the approximate average yearly high water levels under current conditions (in blue) and under the 55-inch (139-centimeter) mean sea level (in red) without factoring in existing shoreline protection. Although the evaluation of SLR is obtained specifically from the CCSM3-A2 global climate model and the extrapolation of SLR using the Rahmstorf model, the results are only dependent on the specific amount of SLR that has occurred and not the climate scenario used. The effects of present or future levees, potential accumulation of sediment and organic matter, and shoreline erosion are not included in this study. Other effects not included in this study include attenuation of short-term variability over inundated areas, which results in a potential overstatement of vulnerability to inundation for areas well removed from the bay's (and the TRIM-2D model's) present-day shoreline, the effect of wind waves, possible effects of tsunamis, geological changes to land surface, including subsidence or uplift, and the effects of potential increased winter flood peaks.

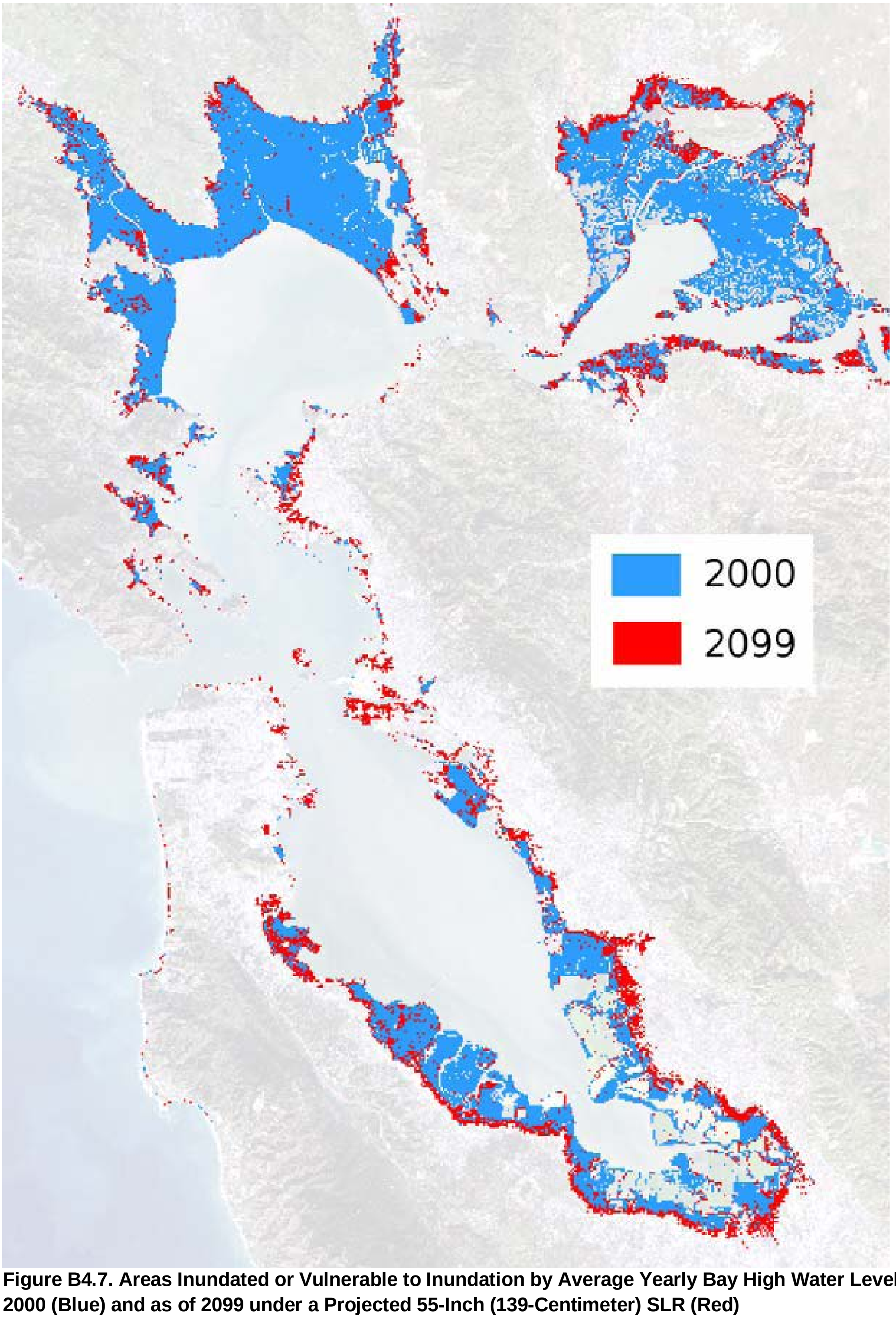

Figure B4.7. Areas Inundated or Vulnerable to Inundation by Average Yearly Bay High Water Levels as of 2000 (Blue) and as of 2099 under a Projected 55-Inch (139-Centimeter) SLR (Red)

Source: Knowles 2009

B4.4 Inundation Mapping

Six inundation scenarios were evaluated as part of this effort as described in Chapter 4. Each SLR scenario—16 inches (40 centimeters) by midcentury and 55 inches (140 centimeters) by the end of the century—is evaluated under three storm/tide conditions: inundation associated with high tides, also known as mean higher high water (MHHW); inundation associated with 100-year extreme water levels, also known as stillwater elevations (100-yr SWEL); and inundation associated with 100-year extreme water levels coupled with wind waves. Three maps were created for each SLR scenario as described above:

- 16-inch SLR (MHHW)
- 16-inch SLR + 100-yr SWEL
- 16-inch SLR + 100-yr SWEL + wind waves
- 55-inch SLR (MHHW)
- 55-inch SLR + 100-yr SWEL
- 55-inch SLR + 100-yr SWEL + wind waves

B4.4.1 SUMMARY OF HYDRODYNAMIC MODEL DATA

This section describes the modeling efforts leveraged for this analysis and presents the model output analysis methodology and results.

B4.4.1.1 LEVERAGED MODEL STUDIES

The inundation mapping effort leveraged existing and readily available model output from two, completed large-scale San Francisco Bay modeling efforts: (1) TRIM2D modeling completed by the USGS for the Computational Assessments of Scenarios of Change for the Delta Ecosystem Project, and (2) MIKE21 modeling completed by DHI for the Federal Emergency Management Agency (FEMA) San Francisco Bay coastal hazard analysis and mapping.

B4.1.1.1 USGS TRIM2D Model

The USGS used a TRIM2D hydrodynamic model to simulate water levels throughout San Francisco Bay over time as sea level rises. The goal of the modeling effort was to estimate potential inundation due to rising sea levels within the coastal areas of the nine San Francisco Bay area counties. The study was not intended to quantify the risk of inundation under future scenarios.

The TRIM2D model was validated over the 1996–2007 period. The hydrodynamic model was driven by hourly water levels at the Presidio that simulate conditions associated with 100 years of SLR. The model simulated a rise in sea level of 55 inches (139 centimeters) over the 100-year period. This projection was based on a combination of climate model outputs, and incorporates astronomical, storm surge, El Niño, and long-term SLR (Knowles 2010). The TRIM2D modeling effort does not include locally generated wind waves within San Francisco Bay. Additional details regarding the USGS TRIM2D modeling effort are available in Knowles (2010).

B4.4.1.1.2 FEMA MIKE21 Model

FEMA is performing new detailed coastal engineering analysis of San Francisco Bay. The goal of the study is to revise and update the flood and wave data for the coastal Flood Insurance Study reports and Digital Flood Insurance Rate Maps. A region-scale hydrodynamic, storm surge and wave model of San Francisco Bay was developed to provide 100-year SWEL (extreme water levels that are exceeded, statistically, once every 100 years), open ocean swells propagating through the Golden Gate, and locally generated wind waves. The region-scale models were developed to provide boundary conditions for onshore coastal hazard analyses.

The FEMA study used the MIKE 21 Hydrodynamic and MIKE 21 Spectral Wave models to simulate water levels and waves for a 31-year continuous period from 1973 to 2004 (Conner et al. 2011). Model input and boundary conditions include the ocean tide level, lower Sacramento River discharge, wind and pressure fields, and various river, creek and tributary discharges. The model was calibrated for tides and storm elevations throughout San Francisco Bay. The wave model was calibrated against a limited number of available wave measurements within the bay. Additional details regarding the FEMA modeling effort are available in DHI (2010) and Conner et al. (2011).

B4.4.1.2 MODEL OUTPUT ANALYSIS

The general approach followed in the analysis of the model output data was to first determine daily tide, extreme tide, and storm conditions for existing conditions at specific model output points within the study area. The derived water level statistics were then projected to future conditions by adding the specified amount of SLR for the midcentury and end-of-century MHHW SLR scenarios. The results at each model output point were then interpolated and extrapolated to create a water surface map for each of the six inundation scenarios. The water surface maps were then used as input in the inundation mapping. The water level analysis at the model output locations is described in this section. The creation of the water surface maps and inundation mapping efforts are described in Section B4.4.2.

B4.4.1.2.1 Model Extraction Points

Output from the USGS TRIM2D and FEMA MIKE21 hydrodynamic modeling efforts was obtained to develop the water surface maps for the inundation mapping scenarios. Noah Knowles (USGS) provided TRIM2D model output at 30 model extraction points, including points along the Alameda County shoreline and along the main San Francisco Bay channel. Figure B4.8 shows the location of the output points within the project area. The extraction points were selected to accurately characterize the spatial variability of water levels throughout the study area and facilitate development of the water surface maps. The extraction points along the Alameda County shoreline were also selected to coincide with model output locations from the existing FEMA MIKE21 model grid so that results from the two models could be compared and used together to more fully characterize the water level and wave conditions within the study area.

USGS TRIM2D model output was provided in 1-hour time steps from January 1, 2000, to December 31, 2099, and consisted of water surface elevations relative to the North American Vertical Datum of 1988 (NAVD88). FEMA MIKE21 model output was provided in 15-minute time steps for water level data and in 1-hour time steps for wave heights. The water level and wave records extended from January 1, 1973, to December 31, 2003. Water surface elevations were provided relative to NAVD88.

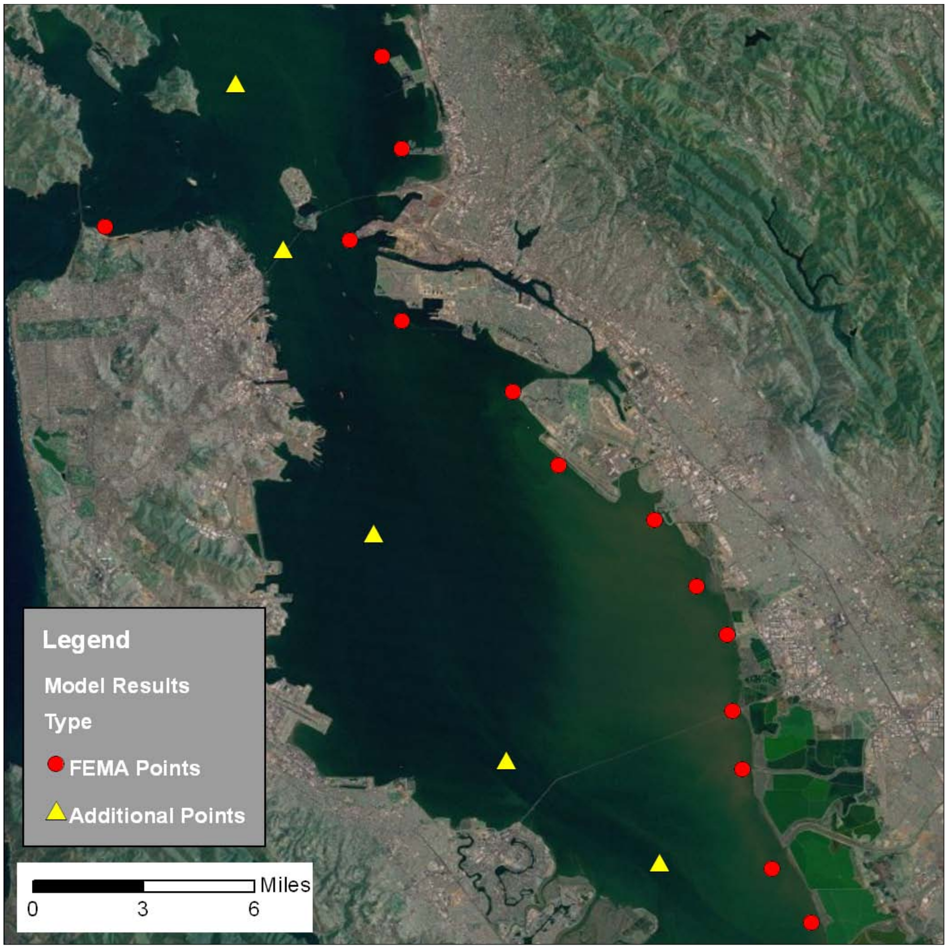

Figure B4.8. DHI and USGS Model Extraction Points within the Project Area

B4.4.1.2.2 USGS TRIM2D Stationarity Analysis

One of the fundamental assumptions in the Knowles (2010) inundation mapping was that of stationarity of the tidal hydraulics over the 100-year simulation period. This assumption was necessary given the methodology used to compute the daily tide and extreme tide statistics at each model output point. For example, under stationary conditions, the daily and extreme tides for existing conditions can be projected into the future simply by adding a specific amount of SLR (e.g., 16 inches [40 centimeters], 55 inches [140 centimeters]). This assumption does not account for factors that may modify the tidal hydraulics over the course of the 100-year simulation period. For example, as sea level rises the mean water depth of the bay will increase, which could affect the way in which the tidal wave propagates throughout the bay. Changes in tidal wave propagation could result in increases or decreases in the tide range at a particular location over time, which would invalidate the stationary assumption inherent in the statistical analysis used to determine daily and extreme tide levels within the study area.

To assess the stationarity assumption, the TRIM2D model time series at each output point was examined to determine if any long-term trends in the elevation of the MHHW tidal datum were observed in the 100-year time series. The following steps were performed at each model extraction point within the study area:

1. The 100-year water level time series was detrended to remove the long-term mean SLR trend (Figure B4.9, lower panel)

2. The detrended time series was segmented into 10-year decadal blocks (e.g., 2000–2010, 2010–2020)
3. The elevation of the MHHW tidal datum was calculated for each decadal block (Figure B4.9, upper panel)
4. A regression line was fit to the decadal MHHW values to determine the long-term trend (Figure B4.9, upper panel)

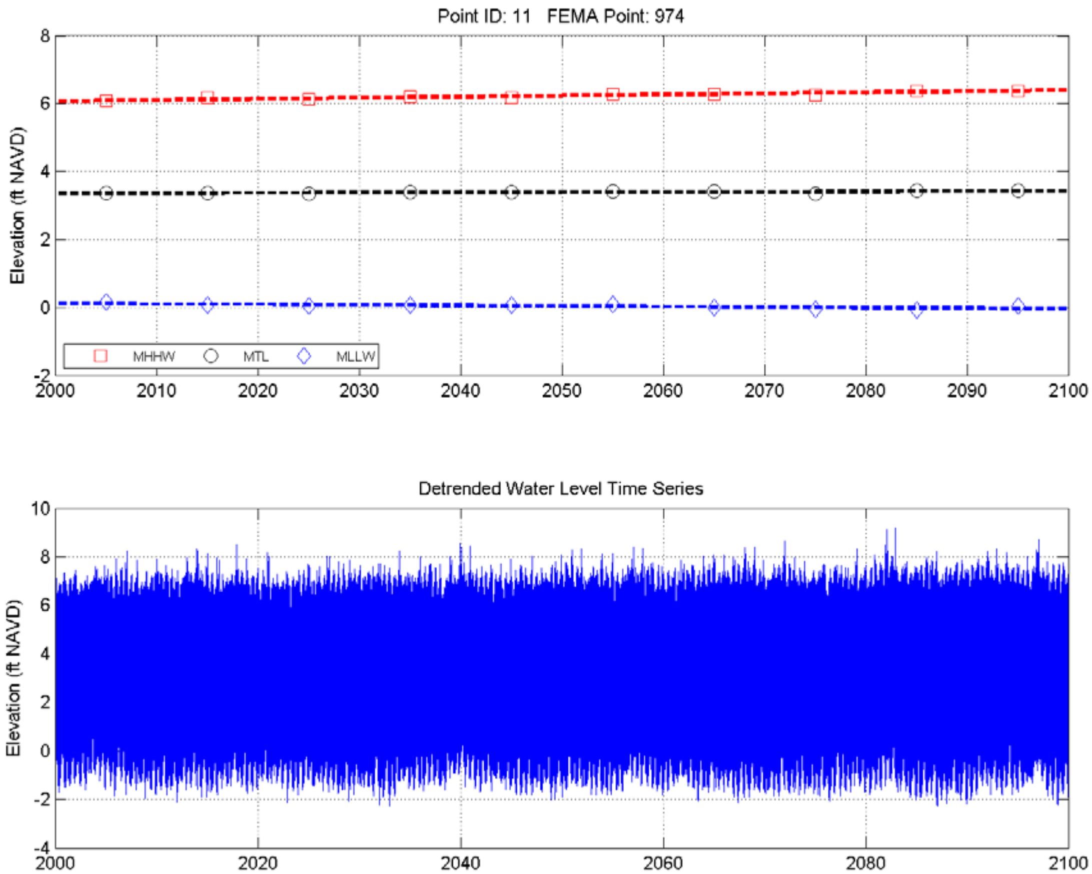

Figure B4.9. Stationarity Analysis and Trends for Sample Model Extraction Point along Alameda County Shoreline

Figure B4.9 shows an example of the analysis and trend determined from the decadal values of the MHHW tidal datum at an example point within the study area. The lower panel shows the 100-year time series with the mean SLR trend removed. The upper panel shows the decadal averaged tidal datums for MHHW, MTL, and MLLW. For each datum, the dashed line is the regression line from which the long-term trend was computed. An average trend of +0.33 foot (+0.1 meter) per century was determined for the MHHW tidal datum along the Alameda County shoreline. This result means that in the TRIM2D modeling, the MHHW tidal datum increased in elevation at a faster rate than mean sea level over the 100-year simulation period. Therefore, based on this analysis, the stationary assumption is not valid within the project area.

Given the importance of maintaining stationarity in the statistical analysis and the large uncertainty in potential future changes in tidal hydraulics due to SLR, it was decided to remove the MHHW trend from the USGS model output prior to statistical analysis. This procedure is described in more detail in Section B.4.4.1.2.3.

B4.4.1.2.3 Daily and Extreme Tide Analysis

Water level time series from the USGS TRIM2D and FEMA MIKE21 simulation periods were analyzed to determine daily and extreme tide levels for existing conditions throughout the study area. Methods of water level analysis are described below.

At each TRIM2D model output point, daily tide and extreme tide levels were computed. The MHHW tidal datum was selected to represent the average daily high tide. Average daily tide elevations for existing conditions were computed using the first 30 years of the detrended simulated time series (i.e., with the mean SLR trend removed). Only the first 30 years were used to avoid complications associated with the stationarity issue discussed in Section B.4.4.1.2.2. MHHW elevations for existing conditions ranged from approximately 6.1 feet to 7.0 feet NAVD from the northern to southern portions of the study area. Results of the daily tide analysis are shown in Figure B4.10.

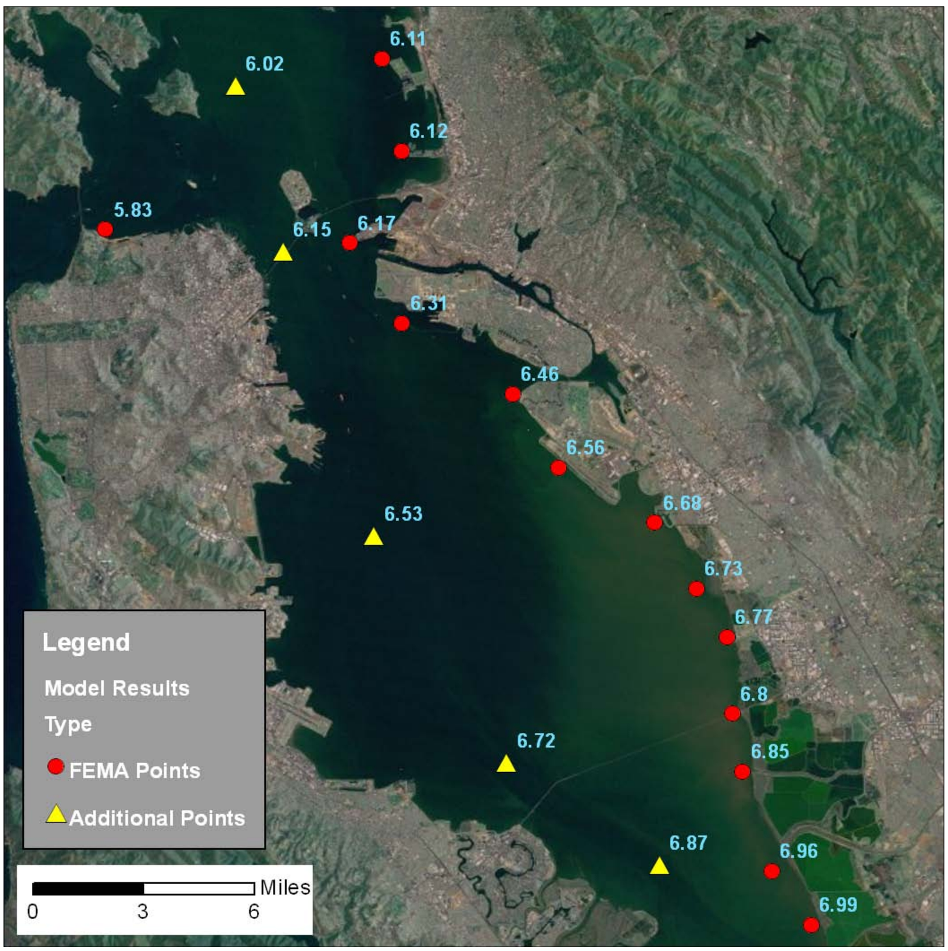

Figure B4.10. Average Daily Tide Elevations (MHHW Tidal Datum) for Existing Conditions Determined from USGS TRIM2D Modeling

Note: Elevations referenced to NAVD88.

The method presented by Knowles (2010) served as the basis for the determination of the extreme tide elevations, and is summarized below. The water level statistic used to represent the extreme tide in this study is the 1 percent-annual-chance water level, commonly referred to as the 100-year SWEL. The following steps were performed to determine the extreme tide elevation at each model extraction point:

1. The 100-year water level time series was detrended to remove the long-term mean SLR trend
2. Annual maxima were extracted based on a July–June "storm year"
3. Annual maxima were adjusted by removing the +0.33 feet per century MHHW trend determined from the stationarity analysis (Section B4.4.1.2.2)
4. A Weibull probability distribution was fit to the annual maxima dataset and extreme tide elevations were determined

Steps 1–3 are illustrated in Figure B4.11. Results of the extreme tide analysis for the USGS TRIM2D model output are shown in Figure B4.12.

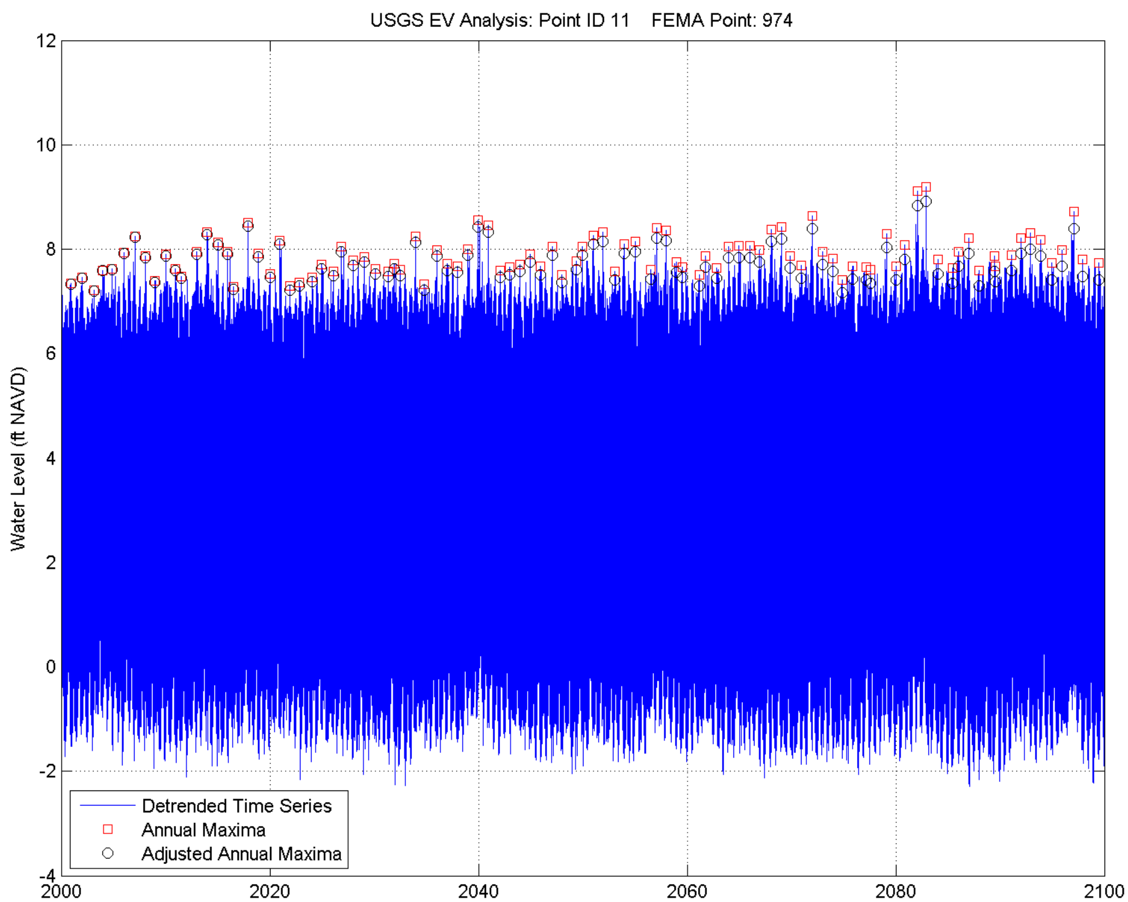

Figure B4.11. Extreme Value Analysis of Annual Maxima for Sample Model Extraction Point along Alameda County Shoreline

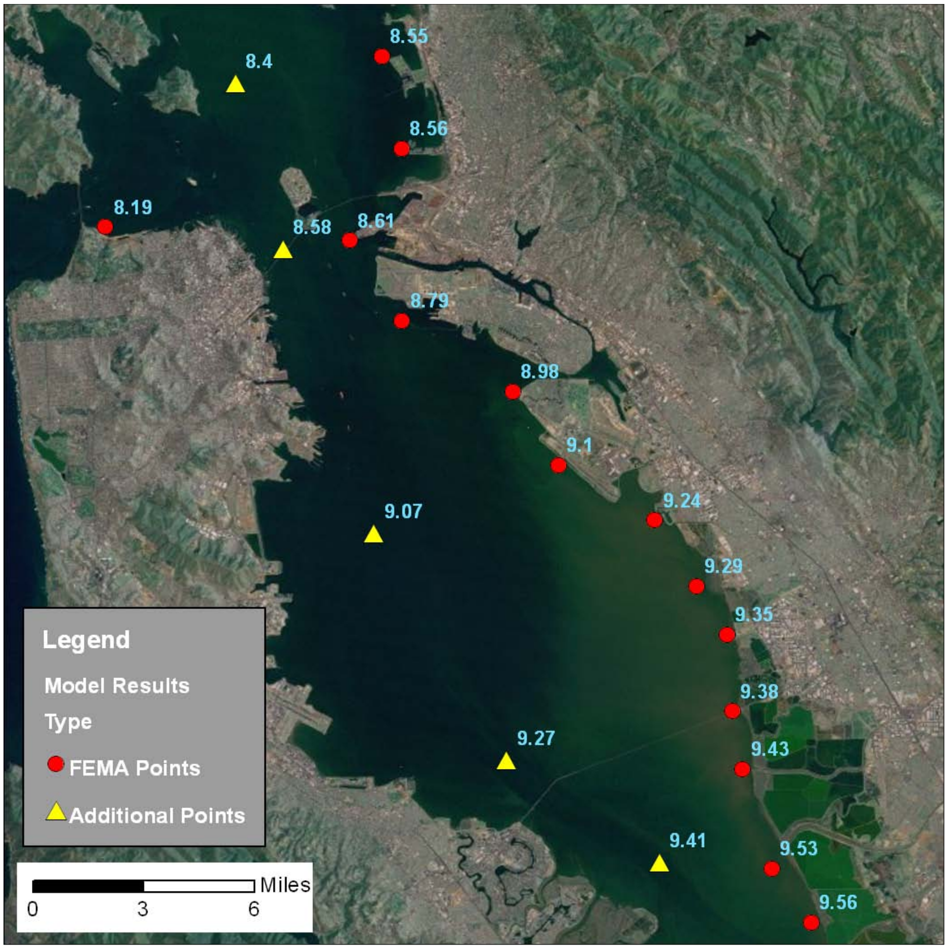

Figure B4.12. Extreme Tide Elevations for Existing Conditions Determined from USGS TRIM2D Modeling

Note: Elevations referenced to NAVD88.

Extreme tide levels were also computed at each of the FEMA MIKE21 model output points. Since the MIKE 21 model boundary condition was detrended to remove SLR in the original modeling effort, it was not necessary to detrend the water level time series prior to statistical analysis. Similarly, no adjustment for stationarity was required. Steps 2 and 4, listed above for the USGS TRIM2D analysis, were carried out to determine the extreme tide levels based on the FEMA water level time series. Results of the extreme tide analysis for the FEMA MIKE21 model output are shown in Figure B4.13.

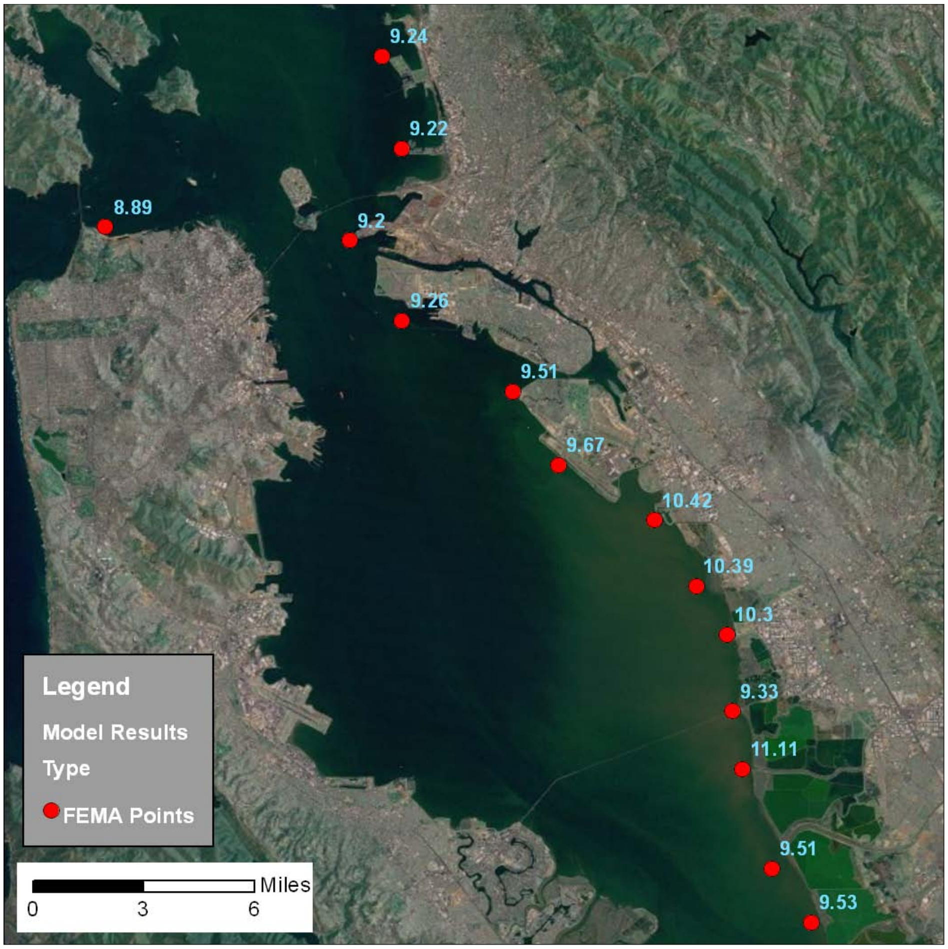

Figure B4.13. Extreme Tide Elevations for Existing Conditions Determined from FEMA MIKE21 Modeling

Note: Elevations referenced to NAVD88.

B4.4.1.2.4 Wind/Wave Storm Scenario Development

Analysis of the USGS TRIM2D and FEMA MIKE21 simulated water levels provides two independent estimates of the extreme tide level along the Alameda County shoreline; however, the two estimates are not directly comparable due to the specifics of each modeling effort. For example, the USGS and FEMA modeling efforts spanned different periods of record: a 100-year projection vs. a 30-year hindcast. Additionally, the FEMA modeling accounted for wind effects including wind setup and wind-wave generation within the bay, whereas the USGS modeling did not. The development of the wind/wave storm scenarios took advantage of these differences to combine the results of the two modeling efforts.

Since the USGS modeling effort spanned a longer period of record, use of the TRIM2D model results was preferable for the extreme tide statistical analysis; however, since theTRIM2D model did not include local wind and wave effects, these components were derived from the FEMA MIKE21 modeling. To develop the storm wave scenario the following additional processes needed to be accounted for along the Alameda shoreline: (1) wind setup, (2) wave setup, and (3) wave height. Wind setup is a component of storm surge that results in an increase in water level due to wind blowing across the water surface and “piling up” water at the shoreline. Similarly, wave setup is an increase in water level at the shoreline due to the presence of breaking waves. These two processes will increase water levels at the shoreline above the extreme tide levels determined from the statistical analysis presented in Section B4.4.1.2.3.

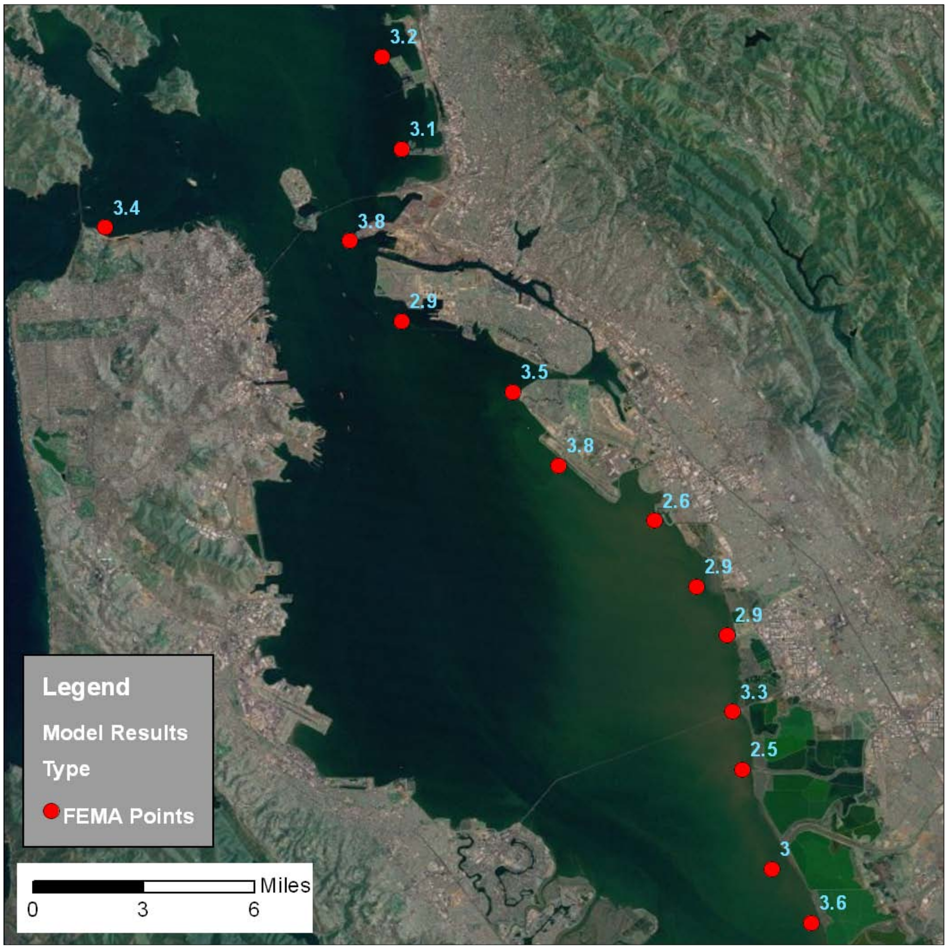

Figure B4.14. Storm Wave Heights for Existing Conditions Determined from DHI MIKE21 Modeling

Note: Wave heights shown in units of feet.

Wind Setup. Since the FEMA MIKE21 model includes wind effects and the USGS TRIM2D model does not, it was assumed the magnitude of wind setup could be estimated as the difference between the extreme tide estimates from the two models. The extreme tide level determined at each model output point from the FEMA MIKE21 and the USGS TRIM2D models was found to differ by -0.1 to 1.7 feet (-0.03 to 0.5 meter), with an average of approximately +0.5 feet (+0.2 meter) within the project area. The contribution of wind setup to the total surge level was therefore estimated to be approximately 0.5 foot (0.2 meter). This value was applied throughout the project area for the wind/wave storm scenarios.

Wave Height. In addition to the water level time series, the time series of wave height was provided at each model output point for the FEMA MIKE21 model. Steps 2 and 4 of the extreme tide statistical analysis were carried out with the wave height time series to determine extreme wave heights. The 10-year wave height was selected as an appropriate storm condition to pair with the 100-year water level to represent the wind/wave storm scenarios. Results of the wave height analysis are shown in Figure B4.14.

10-year wave heights along the Alameda County shoreline were found to range from 2.5 to 3.8 feet (0.8 to 1.2 meters), with an average of 3.5 feet (1.1 meters). For the purposes of FEMA flood mapping, it is assumed that 70 percent of the computed wave height contributes to the total stormwater level. In other words, the wave form is not symmetrical: 70 percent of the wave form is above the average water level, and 30 percent is below. To create the storm scenario water levels in this study, a value equal to 70 percent of the computed wave height from the FEMA MIKE21 model was added to the extreme tide level, along with wind and wave setup.

Wave Setup. While the DHI MIKE21 model simulates the generation of waves by local wind, it is not believed that wave setup is present in the water level time series at the model output points. Wave setup can be roughly estimated using a rule-of-thumb of 17 percent of the offshore wave height (Guza and Thornton 1981). Detailed wave analysis is beyond the scope of this study, so the wave heights at the output locations were used with no modification. Using the range of wave heights shown in Figure B4.14 and the wave setup rule-of-thumb, wave setup was computed to be approximately 0.5 foot (0.2 meter) within the project area. This value was applied throughout the project area for the wind/wave storm scenarios.

Stormwater Level. Once approximate values for wind setup, wave setup, and storm wave height were estimated, these additional water level components were combined with the extreme tide level to estimate the wind/wave storm scenario water levels for existing conditions. The storm scenario represents the coincident occurrence of a 100-year water level coupled with a 10-year wave event. The storm wave scenario is represented as follows:

[Stormwater level] = [100-yr extreme tide] + [wind setup] + [wave setup] + 0.7 x [10-yr wave height]

The resulting stormwater levels with waves for existing conditions are shown in Figure B4.15.

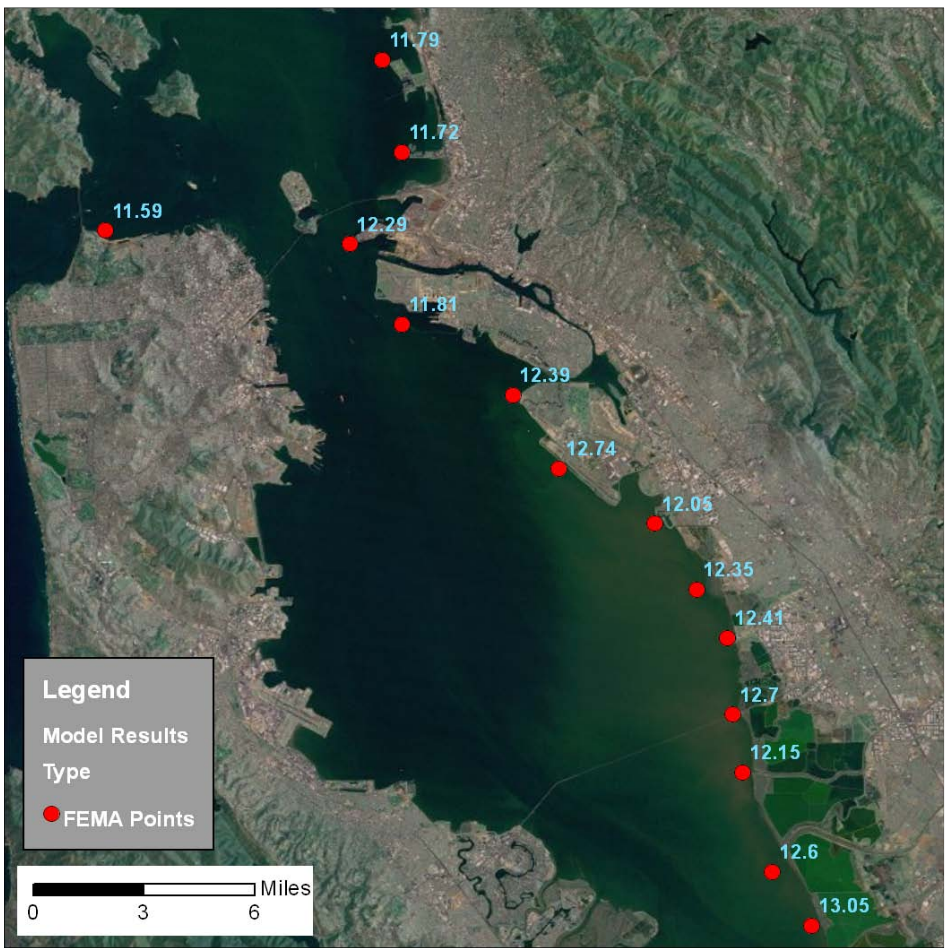

Figure B4.15. Storm Scenario Water Levels with Waves for Existing Conditions

Note: Elevations referenced relative to NAVD88.

B4.4.2 INUNDATION MAP DEVELOPMENT

Once the relevant statistics for the water levels had been generated for the six inundation mapping scenarios, the inundation maps were developed utilizing methodologies developed by the NOAA Coastal Services Center (Marcy et al. 2011).

B4.4.2.1 LEVERAGED TOPOGRAPHIC DATA

USGS managed the LIDAR data collection in south San Francisco Bay. The South Bay LIDAR data were collected in June, October, and November 2010 and provide complete coverage of the coastal areas of Alameda County, up to the 16-foot (5-meter) elevation contour. The collected LIDAR data have a vertical accuracy of +/- 0.07 m, based on the tested RMSEz for all checkpoints (Dewberry 2011). This accuracy exceeds the USGS LIDAR Guidelines and Base Specifications.

The USGS LIDAR and associated Digital Elevation Model (DEM) provide the topographic data for the inundation mapping effort. The bare-earth LIDAR was used for the inundation mapping. In the bare-earth LIDAR, all building and structures (i.e., bridges) have been removed. All vegetation has also been removed as part of the bare-earth LIDAR processing. The resultant DEM is of sufficient resolution and detail to capture the shoreline levees and flood protection assets.

B4.4.2.2 WATER SURFACE DEM CREATION

The initial step in creating the inundation maps relies on creating the inundated water surface, or DEM.

The appropriate amount of SLR (i.e., 16 and 55 inches [41 and 140 centimeters]) was added to the model output data generated for the daily tide (Figure B4.10), extreme tide (Figure B4.12 and 4.13), and extreme storm scenario with wind waves (Figure B4.15) in order to develop the tidal water surface over the open water portion of the bay along the Alameda County shoreline for the six inundation map scenarios:

- 16-inch SLR MHHW (high tide)
- 16-inch SLR + 100-yr SWEL (extreme tide)
- 16-inch SLR + 100-yr SWEL + wind waves (extreme coastal storm event)
- 55-inch SLR MHHW (high tide)
- 55-inch SLR + 100-yr SWEL (extreme tide)
- 55-inch SLR + 100-yr SWEL + wind waves (extreme coastal storm event)

The tidal water surface was then extended inland along a series of transects placed perpendicular to the shoreline to create the water surface elevation over the inundated topography. It should be noted that water surface DEM is simply an extension of the tidal water surface at the shoreline over the inland topography. This represents a conservative estimate of the inland inundated water surface. This exercise does not take into account the associated physics of overland flow, wave dissipation, levee overtopping, or potential shoreline or levee erosion associated with extreme water levels and waves. In order to account for these processes, a more sophisticated modeling effort would be required.

B4.4.2.3 DEPTH AND EXTENT OF FLOODING

Depth of flooding raster files were created by subtracting the land-surface DEM from the water surface DEM. Both DEMs were generated using a 2-meter horizontal resolution with the same grid spacing in order to allow for grid cell to grid cell subtraction. The resultant DEM provides both the inland extent and the depth of inundation (in the absence of considering hydrologic connectivity).

The final step used in creating the depth and extent of flood maps relies on an assessment of hydraulic connectivity. The methodology described by Marcy et al. (2011) employs two rules for assessing whether or not a grid cell is inundated. A cell must be below sea level (or the assigned final water surface DEM elevation value), and it must be connected to an adjacent grid cell that was either flooded or open water. NOAA's methodology applies an "eight-side rule" for connectedness, where the grid cell is considered "connected" if any of its cardinal or diagonal directions are connected to a flooded grid cell. This approach decreases the inundated area over earlier inundation efforts that considered a grid cell to be inundated solely based on its elevation.

The assessment of hydraulic connectivity removes areas from the inundation zone if they are protected by levees or other topographic features that are not overtopped. It also removes areas that are low lying but inland and not connected to an adjacent flooded area.

Chapter 6 presents the final inundation maps for the six scenarios. Low-lying areas that are not hydraulically connected to the inundated areas are shown in green.

The inundation mapping effort was associated with a series of challenges that required careful consideration and attention to detail. In order to develop credible inundation maps, it was important that the levees are adequately resolved in the topographic DEM. A DEM resolution of 2 meters was ultimately used to resolve the levees. However, this resolution was not sufficient to identify floodwalls. Levees that were stair stepped with respect to the DEM grid required the most attention to ensure they were appropriately resolved. The hydraulic connectivity analysis was a useful tool for evaluating whether or not specific levee reaches and/or levee systems were resolved. If the inundated water surface elevation was below a levee crest (i.e., the levee was not overtopped), yet the area behind the levee was not removed from the inundated surface as part of the hydraulic connectivity assessment, the levees (or other topographic features) were investigated in more detail to determine which section(s) were not represented well in the DEM. This type of assessment required an in-depth understanding of the Alameda County shoreline and the shoreline protection assets.

B4.4.3 SHORELINE OVERTOPPING POTENTIAL

Information on the depth of inundation was extracted along the shoreline assets described in Chapter 2 to provide a high-level assessment of the potential for shoreline overtopping. "Overtopping potential" refers to the condition where the water surface elevation associated with a particular SLR scenario exceeds the elevation of the shoreline asset. This assessment is considered a planning-level tool only, as it does not account for the physics of wave runup and overtopping. It also does not account for potential vulnerabilities along the shoreline protection infrastructure that could result in complete failure of the flood protection infrastructure through scour, undermining, or breach after the initial overtopping occurs.

B4.4.3.1 METHODOLOGY

The process and objectives for this analysis was as follows:

- Subdivide the study area into a series of shoreline "systems" – contiguous reaches of shoreline that act together to prevent inundation of inland areas.
- Determine at what locations in the study area shoreline assets are overtopped, causing inundation of low-lying areas landward of the shoreline.
- Determine the length (and percent) of shoreline affected by overtopping.
- For each transportation asset, determine its proximity (i.e., distance) to a segment of overtopped shoreline.
- For each transportation asset, determine which shoreline "system" is responsible for providing protection from inundation.
- Assess the potential for overtopping for each shoreline "system."

The depth of inundation was extracted along the shoreline asset delineation described in Chapter 2. Although the delineation in Chapter 2 defines wetlands and beaches as shoreline asset categories, the delineation for the assessment of overtopping potential was moved inland in select areas to the topographic feature that could control inundation, such as levees, berms, or road embankment crests, which act as barriers to inland inundation.

The shoreline delineation was also subdivided into “systems” that act together to prevent or influence inland inundation. This approach was taken to develop meaningful metrics for assessing the vulnerability of the transportation assets and identifying potential adaptation strategies. A system could be defined as a reach of levee along the shoreline between two adjacent tributaries. Alternatively, a system could be defined as the combination of several asset types (e.g., levees, nonengineered berms, roadway embankments) that act together to influence the inundation of an inland area with similar topographic elevation. Although smaller systems could technically be defined within any given system, the size of the systems were selected to be small enough to provide meaningful metrics relating to the transportation assets, yet large enough to be manageable within the context of this high-level assessment.

The system delineation is shown on the shoreline overtopping potential maps presented in Chapter 6. In total, 28 systems were delineated within the study area ranging in length from approximately 1 to 18 miles. On average, the systems were 4.5 miles in length. The shoreline system delineation was overlain on each of the six inundation depth rasters (i.e., one raster for each of the six inundation scenarios described in Section B4.4), and depth values along the shoreline were extracted from the rasters. Contiguous reaches of overtopped shoreline were grouped together and aggregated as shoreline segments. Overtopping statistics, or metrics, were then calculated for shoreline segments and shoreline systems for each inundation scenario. Given the uncertainty in the modeling results and topography datasets, overtopping depths of less than 0.5 foot (0.2 meter) were excluded from the metrics. The following primary metrics were used to evaluate shoreline overtopping potential:

- *Potential overtopped length of each system*. The length of shoreline that is overtopped within each system can be an indication of the overall vulnerability of the system. For example, a system could have an overtopped length of 0 feet, 100 feet, or 1,000 feet. A system with an overtopped length of 1,000 feet may require more extensive adaptation strategies to reduce inland inundation.
- *Percent of shoreline overtopped for each system*. Although the size of each system may vary, the percent of shoreline overtopped is a useful metric for comparing the performance of the systems under the six storm/tide conditions. For example, a system may have less than 5 percent of its length overtopped under 16 inches (41 centimeters) of SLR and 100-yr SWEL, while 50 percent of its length is overtopped with the addition of waves.
- *Average depth of inundation along a segment*. The average depth of inundation along the shoreline assets was evaluated on a segment level, looking at the actual areas where the shoreline assets could be overtopped. This metric is useful for indentifying the initial flow path for the inland inundation. For example, for the Oakland International Airport, the engineered flood protection levees on the inland edge of Bay Farm Island are overtopped first, resulting in inundation of the airport. Portions of the shoreline system that are not overtopped (overtopping depth = 0) were not included in the average overtopping depth calculation. As sea level rises from the 16” to 55” SLR scenarios, additional lengths of shoreline are inundated within each system; therefore, the average overtopping depth increase between the two scenarios is not equivalent to a 39” increase in sea level.
- *Distance of each transportation asset from the nearest overtopped segment along the shoreline assets*. This metric was evaluated to differentiate between transportation assets that may be protected by the same system. Transportation assets closer to the shoreline could have a more

limited range of potential adaptation strategies, such as building larger engineered flood protection levees along the shoreline or relocating the transportation asset.

B4.4.3.2 DISCUSSION

Chapter 6 presents the resulting shoreline overtopping potential maps with the average depth of overtopping presented by segment for each SLR scenario and storm/tide condition, including a detailed look at five focus areas within the pilot region. The results of the analysis by system are also presented in Chapter 6 for the 16-inch and 55-inch (41- and 140-centimeter) SLR scenarios. Each figure shows three panels, representing the MHHW, 100-yr SWEL, and 100-yr SWEL + wind waves scenarios, to highlight the progression of overtopping along the shoreline under the three storm/tide conditions.

It is important to note that the shoreline overtopping potential metrics were developed to allow for comparison between the SLR scenarios and the three storm/tide conditions. If a system or segment of shoreline is overtopped, regardless of the overall length or depth of overtopping, it could result in the inundation of potentially large low-lying area, especially if the initial overtopping leads to a larger or complete failure of the flood protection infrastructure through scour, undermining, or breach expansion. Therefore, any amount of shoreline overtopping potential should be considered potentially significant.

B4.4.4 UNDERLYING ASSUMPTIONS AND CAVEATS

The inundation maps created for the project area represent advancement over previous inundation maps that characterized the extent of inland inundation due to SLR. Most notably, the new maps include:

- The depth and extent of inundation.
- The maps rely on topographic information from the 2010 USGS LIDAR data. The flood protection levees and other features that could impede flood conveyance are captured in this latest set.
- Wave dynamics along the Alameda County shoreline are considered. Wave heights along the shoreline can exceed 4 feet (1.2 meters) in height; therefore, wave dynamics are important processes to consider when evaluating the potential for shoreline overtopping and inundation in nearshore coastal areas.
- The new mapping effort also benefited from an assessment of hydraulic connectivity, using inundation mapping methodologies developed by the NOAA Coastal Services Center to exclude low-lying areas that are below the inundated water surface elevation, but are not hydraulically connected to the inundated areas.

The inundation maps are only intended as a screening-level tool for performing the vulnerability and risk assessment. Although the inundation maps do account for additional processes, and they rely on new data, they are still associated with a series of assumptions and caveats:

- The bathymetry of San Francisco Bay and the topography of the landward areas, including levees and other flood and shore protection features, would not change in response to SLR and increased inundation (e.g., the morphology of the region is constant over time).
- The maps do not account for the accumulation of organic matter in wetlands, or potential sediment deposition and/or resuspension that could alter San Francisco Bay hydrodynamics and/or bathymetry.
- The maps do not account for erosion, subsidence, future construction, or levee upgrades.
- The maps do not account for the existing condition or age of the shore protection assets. No degradation or levee failure modes have been analyzed as part of the inundation mapping effort.
- The levee heights and the heights of roadways and/or other topographic features that may affect floodwater conveyance are derived from the USGS 2010 LIDAR data, downsampled from a 1-

meter to a 2-meter horizontal grid resolution. Although this data set represents the best available topographic data, and the data have undergone a rigorous quality assurance/quality control process by a third party, the data have not been extensively ground-truthed. Levee crests may be overrepresented or underrepresented by the LIDAR data.

- The inundation depth and extent shown on the MHHW maps are associated with the highest high tides, in an attempt to approximate the maximum extent of future daily tidal inundation. This level of inundation can also be referred to as “permanent inundation,” as it represents the area that would be inundated regularly. Tides in San Francisco Bay exhibit two highs and two lows in any given day, and the daily high tide on any given day may be less than the calculated MHHW tidal elevation.
- The inundation depth and extent shown on the 100-yr SWEL maps is associated with a 100-year extreme water level condition—in other words, an extreme tide level with a 1-percent chance of occurring in any given year. This inundation is considered “episodic inundation” because the newly inundated areas (the areas not inundated under the MHHW scenario) would be inundated only during extreme high tides. It should be noted that extreme tide levels with greater return intervals (i.e., 500-yr SWEL with a 0.2-percent chance of occurring in a given year) can also occur, and would result in greater inundation depths and a larger inundated area.
- The depth of inundation is not shown for the extreme coastal storm event conditions (i.e., 100 yr SWEL + waves) because the physics associated with overland wave propagation and wave dissipation are not included in this study. These processes would have a significant effect on the ultimate depth of inundation associated with the large coastal wave events, resulting in a potential reduction in the depth of inundation in most areas. Alternatively, the wave heights used in this analysis are associated with existing 10-year wave heights, and as sea level rises and bay water depths increase, the potential for larger waves to develop in the nearshore environment increases. This dynamic could result in increases in the depth of inundation, particularly directly adjacent to the shoreline assets.
- The inundation maps focus on the potential for coastal flooding associated with sea level rise and coastal storm events. The inundation maps do not account for localized inundation associated with rainfall-runoff events, or the potential for riverine overbank flooding in the local tributaries associated with large rainfall events.
- The maps do not account for inundation associated with changing rainfall patterns, frequency or intensity as a result of climate change.

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Appendix C – Accompanying Chapter 5 Vulnerability Assessment

C5.1 Introduction

This appendix contains more detail on the sensitivity rating, the full list of assets for which a vulnerability assessment was carried out with their vulnerability rating, and the full consequence methodology.

Note that section numbers are aligned with section numbers in Chapter 5 for ease of navigation.

C5.2 Vulnerability Assessment

C5.2.3 SENSITIVITY

Sensitivity data collected was used to develop sensitivity ratings. The data points for the most consistently provided metrics (level of use [expressed as ADT], O&M costs, and liquefaction susceptibility) were compared and separated into low, medium, and high values with respect to sensitivity. “Higher” values corresponded to higher levels of traffic, O&M costs, and liquefaction susceptibility. If an asset had a value for one of the metrics at the low end, it received one point. If the value was midrange, the asset received two points. If the value was at the high end, it received three points. The total number of points for each asset was compared with the totals for the other assets within the asset type. Assets with a total at the low end of the totals received low ratings, assets with medium range total receive medium ratings, and assets at the high end of the totals received high ratings. The full list of sensitivity ratings assigned for the road assets reviewed can be found in Table C5.3 and Table C5.4.

Note: There is no Table C5.1 or C5.2 (in order to keep table numbering consistent with Chapter 5 for ease of navigation.)

Table C5.3 Sensitivity Rating – Interstates/Freeways and State Routes

Asset (Segment)	Level of Use - Average Daily Traffic Volume	Operations & Maintenance Cost	Liquefaction Susceptibility	Overall Sensitivity (H/M/L)
3 points	> 150,000	> $600,000	Very High	8 or 9 **H**
2 points	50,000–150,000	$300,000–600,000	Very High, Medium	6 or 7 **M**
1 point	< 50,000	< $300,000	Medium	4 or 5 **L**
I-80 (Powell St. to Toll Plaza)	251,000 3 pts.	$673,000 3 pts.	Very High 3 pts.	Point total: 9 **H**
I-880 (I-80 Connection Ramps)	37,500 1 pt.	$211,347 1 pt.	Very High 3 pts.	Point total: 5 **L**
I-880 (7th St. to I-980)	226,000 3 pts.	$211,347 1 pt.	Very High 3 pts.	Point total: 7 **M**
I-880 (Center St. to 7th St.)	125,000 2 pts.	$217,447 1 pt.	Very High 3 pts.	Point total: 6 **M**
I-880 (I-980 to Center St.)	126,000 2 pts.	$294,597 1 pt.	Very High 3 pts.	Point total: 6 **M**
I-880 (Oak St. to 23rd Ave.)	226,000 3 pts.	$548,247 2 pts.	Very High 3 pts.	Point total: 8 **H**
I-880 (High St. to 98th Ave.)	212,000 3 pts.	$677,447 3 pts.	Very High, Medium 2 pts.	Point total: 8 **H**
SR 92 (Clawiter Rd. to Toll Plaza)	86,000 2 pts.	$435,892 2 pts.	Medium 1 pt.	Point total:5 **L**
SR 61 (Bay Farm Island Bridge to 98th Ave.)	20,700 1 pt.	$375,166 2 pts.	Very High 3 pts.	Point total: 6 **M**

Note: Shaded cells indicate that the asset was not carried forward to the risk assessment stage.

Table C5.4 Sensitivity Rating – Arterials, Collectors, and Local Streets

Asset (Segment)	Level of Use - Average Daily Traffic Volume	Operations & Maintenance Cost	Liquefaction Susceptibility	Overall Sensitivity (H/M/L)
3 points	> 20,000	> $5.0 M	Very High	8 or 9 **H**
2 points	5,000– 20,000	$1.0 M– 5.0 M	Very High, Medium	6 or 7 **M**
1 point	< 5,000	≤ $1.0 M	Medium	4 or 5 **L**
West Grand Avenue (I-80 to Adeline St.)	22,912 3 pts.	$2.0 M (30 yrs.) 2 pts.	Very High 3 pts.	Point total: 8 **H**
Hegenberger Road (San Leandro St. to Doolittle Dr.)	18,000 2 pts.	$6.3 M (30 yrs.) 3 pts.	Very High, Medium 2 pts.	Point total: 7 **M**
I-80 Frontage Road (Ashby Ave. to Powell St.)	15,830 2 pts.	$0.9 M (30-yr. equiv.) 1 pt.	Very High 3 pts.	Point total: 6 **M**
Powell Street (West of I-80)	26,520 3 pts.	$1.2 M (30-yr. equiv.) 2 pts.	Very High 3 pts.	Point total: 8 **H**
Mandela Parkway (West Grand Ave. to I-580)	8,030 2 pts.	$1.0 M (30 yrs.) 1 pt.	Very High, Medium 2 pts.	Point total: 5 **L**
Third Street (Mandela Pkwy. to Market St.)	12,000 2 pts.	$0.5 M (30 yrs.) 1 pt.	Very High, Medium 2 pts.	Point total: 5 **L**
Cabot Boulevard	524 1 pt.	$2.3 M (30 yrs.) 2 pts.	Medium 1 pt.	Point total: 4 **L**

Note: Shaded cells indicate that the asset was not carried forward to the risk assessment stage.

VULNERABILITY ASSESSEMENT RATINGS OF SELECTED ASSETS

Table C5.6 shows the list of assets that underwent the vulnerability assessment and the resulting ratings. See Chapter 5 for details of the methodology.

Note: There is no Table C5.5.

Table C5.6 List of assets selected for the vulnerability assessment and their vulnerability ratings

Code (old; new)	Asset category and asset types	Segments chosen	Exposure H/M/L	Sensitivity H/M/L	Inadequate adaptive capacity mid century H/M/L	Overall vulnerability rating H/M/L	Risk profile?
Road Network							
Interstates/ Freeways and State Routes							
T-A-01 R-01	**I-80 (includes part of I-580)**	Powell Street to Bay Bridge Toll Plaza	M	H	H	**H**	**Yes**
T-A-02a	**I-880**	I-80 connection ramps	M	L	M	**M**	**No (Lower vulnerability)**
T-A-02b	**I-880**	7th St to I-980	M	M	M	**M**	**No (Lower vulnerability)**
T-A-02c R-02a	**I-880**	Oak St to 23rd Ave	M	H	M	**M**	**Yes**
T-A-02d R-02b	**I-880**	High St to 98th Ave	M	H	M	**M**	**Yes**
T-A-03 R-03	**SR 92**	Clawiter Rd to San Mateo Bridge Toll Plaza	M	L	H	**M**	**Yes (Link to San Mateo Bridge)**
T-A-04	**SR 61**	Bay Farm Island Bridge to 98th Ave	M	M	H	**M**	**No**
Arterial Examples							
T-A-07 R-04	**West Grand Ave**	I-80 to Adeline St	M	H	M	**M**	**Yes**
T-A-12 R-05	**Hegenberger Rd**	San Leandro Street to Doolittle Dr	M	M	M	**M**	**Combine with Airport Drive**
T-A-13 R-05	**Airport Dr**	Entire facility	M	H	H	**H**	**Combine with Hegenberger Rd**
Examples of Connectors to Isolated Neighborhoods							
T-A-20	**I-80 Frontage Rd**		L	M	M	**M**	**No (Lower vulnerability)**
T-A-21 R-06	**Powell St (City of Emeryville)**	West of I-80	M	H	H	**H**	**Yes**
Collector Examples							
R-07	**Mandela Pkwy**	West Grand to I-580	M	L	M	**M**	Yes
R-08	**Ron Cowan Pkwy**	Entire facility	H	H	H	**H**	Yes
Local Street Examples							
R-09	**Burma Rd**	Entire facility	M	H	H	**H**	Yes
	3rd St	Mandela Pkwy to Market St	M	M	M	**M**	No (Lower vulnerability)

Code (old; new)	Asset category and asset types	Segments chosen	Exposure H/M/L	Sensitivity H/M/L	Inadequate adaptive capacity mid century H/M/L	Overall vulnerability rating H/M/L	Risk profile?
T-A-25 R-10	**Cabot Blvd**		M	L	L	**L**	Yes (PMT request, as in Hayward)
Tunnels and Tubes							
T-A-26 R-11	**Posey Tube (SR 260) - Connects Alameda with East Bay**	All, including approach ramps	H	M	M	**M**	Yes
T-A-27 R-11	**Webster St Tube (SR 61) - Connects Alameda with East Bay**	All, including approach ramps	M	M	M	**M**	Yes
Toll, Interstate and State Bridges of high importance							
T-A-28 R-12	**Bay Bridge (I-80)**	From Toll Plaza until Alameda County boundary	M	H	M	**M**	Yes
T-A-29 R-13	**San Mateo Bridge (SR 92)**	From Toll Plaza until Alameda County boundary	L	M	M	**M**	Yes
Alameda Bridges							
T-A-31	**Park Street Bridge**		L	L	L	**L**	No (low vulnerability)
T-A-32 R-14	**Bay Farm Island Bridge**	Entire facility, including adjacent bicycle bridge	M	H	H	**H**	Yes
Transit Assets							
BART Rail Alignment							
T-B-17	BART At Grade: east approach of Oakland Wye	Tunnel portal only	L	Lack of data	H	**M**	No (lower vulnerability)
T-B-18 T -01	BART Sub Grade: Transbay Tube		**M**	Lack of data	**H**	**HM**	Yes
T-B-20 T -02	BART Elevated: between Transbay Tube and Oakland Wye	Elevated structure between I-880 overcrossing and I-880 undercrossing	M	Lack of data	H	**MH**	Yes

Code (old; new)	Asset category and asset types	Segments chosen	Exposure H/M/L	Sensitivity H/M/L	Inadequate adaptive capacity mid century H/M/L	Overall vulnerability rating H/M/L	Risk profile?
T-B-XX R-05	Future BART Line - Oakland Airport Connector	Route serving/ crossing SLR exposure area	**M**	Lack of data	**M**	**M**	Yes, combined with Hegenberger Rd and Airport Dr
Rail Stations							
T-B-22	Lake Merritt BART Station	Not in SLR exposure area, groundwater currently being pumped	N/A	Lack of data	M	**N/A**	No (Lower vulnerability)
T-B-23 T-03	West Oakland BART Station	Access area and station in or close to SLR exposure area	L	Lack of data	H	**M**	Yes
T-B-24 T-04	Coliseum/ Airport BART Station	Access area and station in or close to not in SLR exposure area	L	Lack of data	H	**M**	Yes
T-B-26 T-05	Oakland Jack London Square Amtrak Station	Access area and station in or close to SLR exposure area	M	Lack of data	M	**M**	Yes
Rail – Passenger and Freight (Capitol Corridor) Amtrak and UP rail lines; Oakland Port Connections							
T-B-28 T-06	Union Pacific Martinez Subdivision	10th St to 34th St Crossover	M	Lack of data	H	**HM**	Yes
T-B-29 T-07	Union Pacific Niles Subdivision	Magnolia Crossover to East Oakland Yard	M	Lack of data	H	**HM**	Yes
T-B-30	Union Pacific Niles Subdivision	Coliseum Segment	M	Lack of data	M	**M**	No (Lower vulnerability)
Ferry Terminals							
T-B-32 T-08	Jack London Square		M	H	H	**H**	Yes
T-B-33 T-09	Alameda Gateway (including P&R, bike, ADA access)		M	M	H	**M**	Yes

Code (old; new)	Asset category and asset types	Segments chosen	Exposure H/M/L	Sensitivity H/M/L	Inadequate adaptive capacity mid century H/M/L	Overall vulnerability rating H/M/L	Risk profile?
Facilities							
Traffic Management Centers (includes signal and traffic control centers)							
T-C-01	City of Alameda TMC		L	Lack of data	L	**L**	No (lower vulnerability)
Bus Service Facilities (Includes Bus Yards and Depots)							
T-C-05 F-01	AC Transit Maintenance (1100 Seminary)		M	Lack of data	M	**M**	Yes
Rail – Passenger and Freight (Capitol Corridor) Yards and Depots							
T-C-08 F-02	BNSF Intl Gateway Intermodal Yd		L	Lack of data	H	**M**	Yes
T-C-09 F-03	Capitol Corridor Norcal O&M Yard		M	Lack of data	H	**HM**	Yes
T-C-10 F-04	7th Street Highway and Railroad Pumps		L	Lack of data	H	**M**	Yes
Bicycle and Pedestrian Facilities							
Bike and Pedestrian Routes/Trails							
T-D-01 B-01	Lake Merritt Connector Trail		H	H	H	**H**	Yes
Class I portions of Bay Trail (existing and proposed), potential segments							
	Oakland - Jack London Square Ferry to Estuary Park		M	Lack of data	M	**M**	No (Lower vulnerability)
	Oakland - Embarcadero Cove to Union Point Park		M	Lack of data	M	**M**	No (Lower vulnerability)
	Oakland - East Creek Point to Swan Way/Airport Channel		M	Lack of data	H	**HM**	No (Lower vulnerability)
T-10	Alameda - Ferry Connector		M	Lack of data	M	**M**	Yes (Included with ferry terminal)
B-02	Bay Trail (located on old levees along the Hayward shoreline)		H	Lack of data	H	**H**	Yes
T-D-02	Alameda Creek Trail		M	Lack of data	H	**HM**	No (Lower vulnerability)

C5.3 Risk Assessment

C5.3.3 CONSEQUENCE METHODOLOGY

Assets in italics were assessed but risk profiles are not being produced for them.

Capital Improvement Cost

Data on capital improvement cost is quite complete for the road network, and distributes quite evenly along the following rating scale:

- less than $20 million L – Minor Consequence, Rating 1

- $20 to $50 million M – Moderate Consequence, Rating 3
- greater than $50 million H – Major Consequence, Rating 5

Since the road network represents the majority of assets, this rating scheme is applied without modification to all assets, especially since data is not complete for all assets.

Ratings assigned by professional judgment:

Asset name	Rating	Rationale
Airport Drive	3	It includes underpass/overpass structures
Ron Cowan Parkway	3	It includes an underpass
Burma Road	1	It is a local street at grade
Park Street Bridge	*3*	*The same ranking as Bay Farm Island Bridge*
BART Oakland Wye South Tunnel Portal and O&M Shop	*5*	*Cost likely >$50 million in $2011*
BART Transbay Tube	5	One of the most expensive components of the BART system
BART West Oakland Elevated Structure	3	Excluding station, cost likely $20-50 million in $2011
BART Stations	5	The West/Dublin Pleasanton Station cost $106 million[1]
Oakland Jack London Square Amtrak Station	1	At-grade HST station est. to cost $15 million
UP Martinez Subdivision	3	At-grade railroad likely to cost at least $20 million per mile
UP Niles Subdivision	5	At-grade railroad plus bridge over Lake Merritt inlet to cost at least $50 million
Coliseum Rail Segment	*3*	*At-grade railroad plus three bridges over channels, $20-50 million*
City of Alameda TMC	*1*	*Office space / communications equipment likely less than $20 million*
AC Transit Maintenance Facility	5	A new bus maintenance facility in Nevada cost $87 million[2]
BNSF International Gateway Intermodal Yard	5	Likely to cost at least as much as a bus facility
Capitol Corridor Northern Calif. O&M Yard	5	Likely to cost at least as much as a bus facility
7th Street Highway and Railroad Pumps	1	No structures of appreciable size, likely <$20 million
Bay Trail	1	Bay Trail segments, even with bridges, likely to cost <$20 million[3]

Time to Rebuild

Data on time to rebuild is quite complete for the road network, and only three time periods were indicated: 84 months, 60 months, and 2 years. This provides the basis for the following rating scale:

- 2 years or less L – Minor Consequence, Rating 1
- 2 to 5 years M – Moderate Consequence, Rating 3
- greater than 5 years H – Major Consequence, Rating 5

[1] http://www.bart.gov/news/articles/2011/news20110121.aspx
[2] http://www.lasvegassun.com/news/2009/aug/26/rtc-opens-new-bus-maintenance-facility/
[3] The Stevens Creek Trail in Santa Clara County, with a length at least as long as any of the specified Bay Trail segments, cost about $10 million: http://baytrail.abag.ca.gov/vtour/map3/access/Btmtnvw/Btmtvw1.htm

Since the road network represents the majority of assets, this rating scheme is applied without modification to all assets, especially since data is not complete for all assets.

Ratings assigned by professional judgment:

Asset name	Rating	Rationale
Airport Drive	3	It includes underpass/overpass structures
Ron Cowan Parkway	3	It includes an underpass
Burma Road	1	It is a local street at grade
Cabot Road	3	Time to rebuild considered to be longer than stated in data, to include proposed interchange
Park Street Bridge	*5*	*Same ranking as Bay Farm Island Bridge*
BART Oakland Wye South Tunnel Portal and O&M Shop	*3*	*Could likely be rebuilt within 5 years*
BART Transbay Tube	5	Construction originally took 9 years[4]
BART West Oakland Elevated Structure	3	Could likely be rebuilt within 5 years
BART Stations	3	Construction of the West/Dublin Pleasanton Station was planned at 3 yrs.[5]
Oakland Jack London Square Amtrak Station	3	Opened in 1994, 5 yrs. after Loma Prieta Earthquake[6]
UP Martinez Subdivision	1	At-grade with no bridges, could likely be rebuilt within 2 years
UP Niles Subdivision	3	At-grade, bridge over Lake Merritt inlet, could likely be rebuilt <5 yrs.
Coliseum Rail Segment	*3*	*At-grade plus 3 bridges over channels, could likely be rebuilt <5 yrs.*
City of Alameda TMC	*1*	*Could be relocated within a short time frame less than 2 years*
AC Transit Maintenance Facility	3	Could likely be rebuilt within 5 years
BNSF International Gateway Intermodal Yard	5	Would likely take at least 5 years to rebuild
Capitol Corridor Northern Calif. O&M Yard	3	Could likely be rebuilt within 5 years
7th Street Highway and Railroad Pumps	1	No structures of appreciable size, could likely be rebuilt <2 years
Bay Trail	1	Bay Trail segments, even with bridges, could likely be rebuilt within 2 years

Public Safety

Public Safety consequence is assessed based on "Lifeline Highway Routes" as defined by Caltrans.[7] Only two of the selected assets are so designated: the Bay Bridge, and I-80 from the Bay Bridge Toll Plaza to the Project Boundary. These assets are assigned "Major Consequence, Rating 5". Additionally, some assets are designated as "evacuation routes" in the Oakland General Plan or the Alameda Emergency Operations Plan; these assets are assigned "Moderate Consequence, Rating 3". It is considered that non-lifeline freeways fulfill a public safety function at least as great as the city-defined

[4] http://en.wikipedia.org/wiki/Transbay_tube
[5] Actual construction took five years due to faulty construction: http://en.wikipedia.org/wiki/West_Dublin_/_Pleasanton_(BART_station)
[6] The station was built to replace the 16th Street Station, which was condemned due to earthquake damage: http://www.greatamericanstations.com/Stations/OKJ/Station_view
[7] Lifeline Highway Routes Map, Caltrans District 4 Office of System and Regional Planning

evacuation routes; they are automatically assigned “Moderate Consequence, Rating 3” as well. All other assets are assigned “Minor Consequence, Rating 1”.

Asset name	Rating	Rationale
Bay Bridge / I-80 segment	5	Caltrans Lifeline Highway, Emeryville Evacuation Route
I-880 segments and 7th Street Highway and Railroad Pumps	3	Freeway
SR 92	3	Freeway
West Grand Ave	3	Oakland Evacuation Route
Hegenberger Rd / Airport Dr	3	Oakland Evacuation Route
Posey / Webster Tubes	3	Alameda Evacuation Route
San Mateo Bridge	3	Freeway
Bay Farm Island Bridge	3	Alameda Evacuation Route
BART Transbay Tube / Elevated BART Line between	5	Regional significance, alternative to Bay Bridge
Transbay Tube and Oakland Wye		
Ferry terminals	3	“Immediately after a disaster strikes, ferries will be critical to helping the Bay Area get back on its feet and keep the economy moving. When roads, bridges, or BART fail, waterways may be the only safe transportation option.”[8]

Economic Impact – Goods Movement

Data on truck volumes is quite complete for the road network, with the assets dividing fairly evenly between those carrying less than 5,000 trucks per day and those carrying greater truck volumes. This provides the basis for the following rating scale:

- less than 5,000 AADTT   M – Moderate Consequence, Rating 3
- more than 5,000 AADTT   H – Major Consequence, Rating 5

“Minor Consequence, Rating 1” is reserved for local streets and assets that are not used for goods movement, as listed below.

Ratings assigned by professional judgment:

Asset name	Rating	Rationale
West Grand Avenue	5	Connects Port of Oakland (seaport) to freeway network
Hegenberger Road	5	Connects Port of Oakland (air freight) to freeway network
Airport Drive	5	Connects Port of Oakland (air freight) to freeway network
I-80 Frontage Road	*1*	*Local street*
Powell Street	1	Local street
Mandela Parkway	1	Local street
Ron Cowan Parkway	5	Connects Port of Oakland (air freight) to freeway network
Burma Road	5	Connects Port of Oakland (seaport) to freeway network
3rd Street	*1*	*Local street*
Cabot Boulevard	1	Local street
Park Street Bridge	*3*	*Same ranking as Bay Farm Island Bridge*
Rail segments	5	Each connect the Port of Oakland to the regional/national rail network
BNSF International Gateway Intermodal Yard	5	By definition crucial to goods movement
7th Street Hwy/RR Pumps	5	Supports I-880 and UPRR; both carry high goods volumes

[8] http://www.watertransit.org/aboutUs/aboutUs.aspx

Asset name	Rating	Rationale
BART lines and BART stations Oakland Jack London Square Amtrak Station Ferry terminals *City of Alameda TMC* AC Transit Maintenance Facility Capitol Corridor Northern Calif. O&M Yard Bay Trail segments	1	Not used for goods movement

Economic Impact – Commuter Route

Ridership data is quite complete for transit assets and for bus routes using the road network. To determine "ridership" for road network assets, the sum of the daily ridership of each bus route using a particular road segment is used. For the BART lines, the daily line load is used; for BART stations, the sum of daily entries and exits is used. Annual ridership for the ferries is divided by 365. The results range considerably, from a few dozen transit riders to over 175,000 per day. Professional judgment is used to divide the assets between those carrying 10,000 or fewer riders per day, and those carrying greater levels of ridership:

- 10,000 or fewer daily riders M – Moderate Consequence, Rating 3
- more than 10,000 daily riders H – Major Consequence, Rating 5

In addition, it is considered that all freeways and both bridges crossing the Bay carry high levels of automobile-based commuter traffic and are automatically assigned "Major Consequence, Rating 5", regardless of the level of transit ridership they carry. This scheme rates all existing BART assets with "Major Consequence, Rating 5", as well as the Posey and Webster Street Tubes, which, though not freeways, also carry considerable volumes of auto-based commute traffic. Since Hegenberger Road, Airport Drive, and the Future Oakland Airport BART Connector are being profiled together, Rating 5 is applied, reflecting the expected future ridership of the new BART line. "Minor Consequence, Rating 1" is reserved for assets that are not used by transit vehicles, as listed below.

Ratings assigned by professional judgment:

Asset name	Rating	Rationale
AC Transit Maintenance Facility	5	Critical to providing AC Transit service
Rail segments	3	Daily ridership for the entire Capitol Corridor is 4,330[9]
Capitol Corridor Northern Calif. O&M Yard	3	Supports Capitol Corridor service, ranked with 3
7th Street Hwy/RR Pumps	3	Supports I-880, ranked with 3
I-80 Frontage Road Burma Road *3rd Street* *City of Alameda TMC* BNSF International Gateway Intermodal Yard Bay Trail segments	1	Not used by transit vehicles While certain Bay Trail segments may provide more connectivity for commuters accessing transit than others, overall the volumes are considered minor

Socioeconomic Impact

Socioeconomic consequence is assessed based on MTC Communities of Concern[10] (CC) and MTC data on household car ownership[11] (serving as a proxy for transit dependence, TD). Assets are also

[9] http://en.wikipedia.org/wiki/Capitol_Corridor

considered based on whether they provide access to transit ("Local transit" stopping at frequent intervals along a street) or only facilitate "pass-through" transit (such as buses on freeways, bridges or in tunnels). For this purpose, "premium" transit services (Capitol Corridor and ferries) are not included, as they do not typically serve transit-dependent populations.

"Minor Consequence, Rating 1" applies if:

- an asset is not in a CC/TD area, but provides access to, or facilitates "pass through traffic" for just one transit line; or
- is in a CC/TD area but does not facilitate transit

"Moderate Consequence, Rating 3" applies if:

- an asset is in a CC/TD area and provides access to just one transit line; or
- facilitates "pass through" traffic for multiple transit lines (whether or not in a CC/TD area)

"Moderate Consequence, Rating 5" applies if:

- an asset is in a CC/TD area and provides access to multiple transit lines.

Asset name	Rating	Rationale
I-80 (Powell St to Toll Plaza)	3	TD and Pass-through transit (multiple lines)
I-880 (Oak St to 23rd Ave)	3	CC + TD area and Pass-through transit (multiple lines)
I-880 (HighSt to 98th Ave)	3	TD area and Pass-through transit (multiple lines)
SR 92	1	Pass-through transit
West Grand Ave	3	TD area and Local transit
Hegenberger Rd / Airport Dr / Future OAK BART Connector	5	CC + TD area and Local transit (multiple lines)
Powell St	1	Local transit
Mandela Pkwy	3	CC + TD area and Local transit
Ron Cowan Pkwy	3	TD area and Local transit
Burma Road	1	TD area
Cabot Blvd	3	CC area and Local transit
Posey / Webster Tubes	3	CC area and Pass-though transit (multiple lines)
Bay Bridge	3	Pass-through transit (multiple lines)
San Mateo Bridge	1	Pass-through transit
Bay Farm Island Bridge	3	Pass-through transit (multiple lines)
BART Transbay Tube	3	Pass-through transit (multiple lines)
Elevated BART Line between Transbay Tube, Oakland Wye	3	CC + TD area and Pass-through transit (multiple lines)
West Oakland BART Station	5	CC + TD area and Local transit (multiple lines)
Coliseum/Oakland Airport BART Station	5	CC + TD area and Local transit (multiple lines)
Oakland Jack London Square Amtrak Station	1	CC area and "Premium" transit
UP Martinez Subdivision	1	TD area and Pass-through "Premium" transit
UP Niles Subdivision	1	CC area and Pass-through "Premium" transit
Jack London Square Ferry Terminal	1	CC area and Local "Premium" transit
Alameda Gateway Ferry Terminal	1	CC area and Local "Premium" transit

[10] http://www.mtc.ca.gov/planning/snapshot/ (note that this definition is subject to change but information is correct for current (August 2011) definitions.

[11] MTC data on household car ownership by Census Block (2011) was divided into quintiles. If an asset is located in (a) Census Block(s) in the lower three quintiles, corresponding to Census blocks where 81 percent or fewer of the households own cars, it is considered to be in an area with low car ownership.

Asset name	Rating	Rationale
AC Transit Maintenance Facility	3	CC + TD area, supporting Local transit (multiple lines)
BNSF International Gateway Intermodal Yard	1	TD area
Capitol Corridor Northern California O&M Yard	1	CC area, supporting “Premium” transit
7th Street Highway and Railroad Pumps	1	CC + TD area

C5.4 Risk Profiles

Risk profiles were created for the following assets:

Code	Asset Category and Asset Types	Segments Chosen	Final Risk Rating
Road Network (R)			
R-01	I-80 (includes part of I-580)	Powell Street to Bay Bridge Toll Plaza	High
R-02a	I-880	Oak St to 23rd Ave	High
R-02b	I-880	High St to 98th Ave	High
R-03	SR 92	Clawiter Rd to San Mateo Bridge Toll Plaza	Medium
R-04	West Grand Ave	I-80 to Adeline St	Medium
R-05	Hegenberger Rd Airport Dr Future BART Line - Oakland International Airport Connector	San Leandro Street to Doolittle Dr Entire facility Route serving/crossing SLR exposure area	Medium Medium Medium
R-06	Powell St (City of Emeryville)	West of I-80	Low
R-07	Mandela Pkwy	West Grand Ave to I-580	Low
R-08	Ron Cowan Pkwy	Entire facility	Medium
R-09	Burma Rd	Entire facility	Low
R-10	Cabot Blvd	Entire facility	Medium
R-11	Posey Tube (SR 260) Webster St Tube (SR 61)	All, including approach ramps	High High
R-12	Bay Bridge (I-80)	From Toll Plaza until Alameda County boundary	High
R-13	San Mateo Bridge (SR 92)	From Toll Plaza until Alameda County boundary	Medium
R-14	Bay Farm Island Bridge	Entire facility, including adjacent bicycle bridge	Medium
Transit (T)			
T -01	BART Transbay Tube	Entire facility	High
T -02	Elevated BART Line between Transbay Tube and Oakland Wye	Elevated structure between I-880 overcrossing and I-880 undercrossing	Medium
T-03	West Oakland BART Station	Entire facility	Medium

Code	Asset Category and Asset Types	Segments Chosen	Final Risk Rating
T-04	Coliseum/Airport BART Station	Entire facility	Medium
T-05	Oakland Jack London Square Amtrak Station	Entire facility	Low
T-06	UP Martinez Subdivision	Emeryville Segment (I-580 to 14)	Medium
T-07	UP Niles Subdivision	Oakland Segment (17-23)	Medium
T-08	Jack London Square Ferry Terminal	Entire facility	Low
T-09	Alameda Gateway Ferry Terminal (including Park &Ride, bike, ADA access)	Entire facility	Low
Facilities (F)			
F-01	AC Transit Maintenance (1100 Seminary)	Not Applicable	Medium
F-02	Burlington Northern Santa Fe Intl Gateway Intermodal Yard	Not Applicable	Medium
F-03	Capitol Corridor Norcal O&M Yard	Not Applicable	Medium
F-04	7th Street Highway and Railroad Pumps	Not Applicable	Medium

Figure C5.1 provides a glossary of the information provided in each risk profile. (For a full explanation of each term, refer to the relevant parts of Chapters 4 and 5.) Note that there may be symbols in the thumb images that are not explained. For the full legend, please see the inundation and overtopping maps in Chapter 6 of the technical report. The following pages contain risk profiles for each of these assets.

Risk Profile Glossary

Asset Location/Jurisdiction Location of the asset in the region/agency responsible for the asset	
Summary Summarizes the technical information on the risk profile in a couple of sentences	
Characteristics This section lists the functionality of the asset selecting from: • Lifeline route • Mass evacuation plan route • Goods movement • Transit routes • Bike route • Commuter route • Regional importance • Socioeconomic importance: supports transit-dependent populations	

Sensitivity: Low /Medium/High – provides the overall sensitivity rating allocated for the asset	
Year Built	Year
Level of Use	
Peak Hour AADT (Annual Average Daily Traffic AADTT (Annual Average Daily Truck Traffic)	Number
Seismic Retrofit	Yes / No
Annual Operations & Maintenance	Cost $
Liquefaction Suceptibility	VH = very high H = high M = moderate L = low
Exposure: Low /Medium/High – provides the overall exposure rating allocated for the asset	
Maximum Inundation Depths	
16" + MHHW 16" + 100-yr SWEL 16" + 100-yr SWEL + wind waves	ft ft Yes/No
55" + MHHW 55" + 100-yr SWEL 55" + 100-yr SWEL + wind waves	ft ft Yes/No
Inadequate Adaptive Capacity (16" SLR): Rating Notes on alternative routes available if asset is inundation	
Vulnerability Rating (midcentury): Low /Medium Low / Medium/ Medium High / High	

Images shown on each risk profile

- Context map showing where the asset is in the subregion
- Photograph(s) of the asset
- Map thumbnail showing projected inundation with 16-inch SLR + 100-yr SWEL
- Map thumbnail showing projected inundation with 55-inch SLR + 100-yr SWEL
- Map thumbnail showing projected overtopping with 16-inch SLR + 100-yr SWEL (light blue)
- Map thumbnail showing projected overtopping with 55-inch SLR + 100-yr SWEL

*Note that there may be symbols in the thumbnail images that are not explained – for the full legend please see the inundation and overtopping maps in Chapter 6.

Risk Profile Glossary

Consequence Rating (out of 5): Number between 0 and 5 Ranges of consequence or impact - major (5), moderate (3) and minor (1) were developed for each of the impacts below.	
Capital improvement cost	Cost to restore to same design standard/ infrastructure type.
Time to rebuild	To original condition, based on 84-, 60-, and 24-month estimates
Public safety	Lifeline or evacuation route
Economic impact - goods movement	Based on average annual daily truck traffic (AADTT) data
Economic impact - commuter route	Daily ridership figures (also all freeways, bridges, tubes assigned major impact)
Socioeconomic impact	Based on MTC communities of concern, MTC data on household car ownership and whether providing a transit route
Risk Rating: High / Medium / Low (from combination of "likelihood" and "consequence") rating	

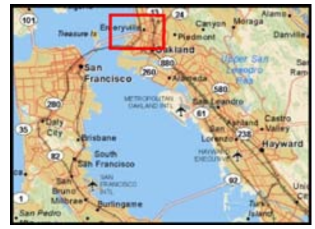
Shoreline Asset "Overtopping" Analysis ***(see Section 4.3.2 for more detail)***	
Proximity of transportation asset to overtopped shoreline asset (distance)	***16" + 100-yr SWEL*** ft Transportation assets that are closer to the shoreline could have a higher likelihood of future inundation
	55" + 100-yr SWEL ft
Length overtopped (% of System)	***16" + 100-yr SWEL*** ft (%) The greater the percentage, potentially the more at risk the asset is
	55" + 100-yr SWEL ft (%)
Average depth of overtopping	The average depth of inundation along the overtopped portion of the shoreline assets within a particular system. Portions of the shoreline system that are not overtopped (overtopping depth = 0) are not included in the average overtopping depth calculation. As sea level rises from the 16" to 55" SLR scenarios, additional lengths of shoreline are inundated within each system; therefore, the average overtopping depth increase between the two scenarios is less than the 39" increase in sea level.
	16" + 100-yr SWEL ft The deeper the overtopping, potentially the more at risk the asset is
	55" + 100-yr SWEL ft
System responsible for inundating transportation asset (See overview map)	Number of System: The study area is divided into 28 shoreline "systems" – contiguous reaches of shoreline that act together to prevent inundation of inland areas, ranging in length from approximately 1 to 18 miles. Section 6.5

Future Projects
Description of any future projects anticipated for the asset**.**

Figure C5.1 Risk Profile Glossary: Asset Name (Asset Code)

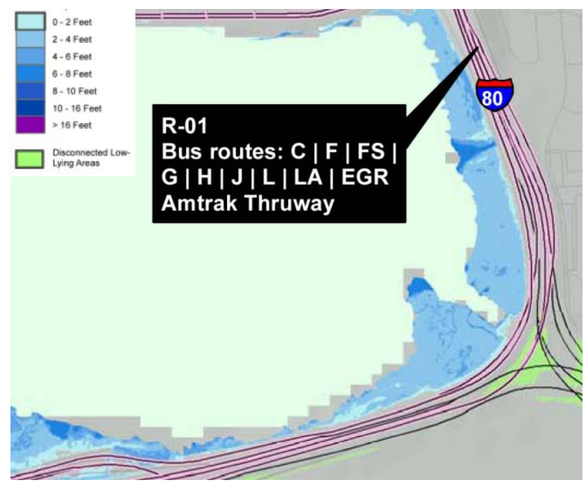
Asset Risk Profile

Interstate 80 (R-01)

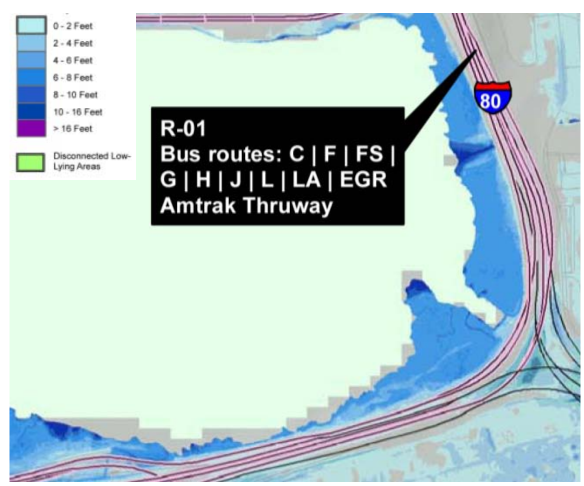


Asset Location / Jurisdiction Oakland, Emeryville / FHWA, Caltrans	
Summary Interstate 80 (I-80) is a freeway that connects Alameda County to the greater region. This profile considers the segment of I-80 between the Bay Bridge Toll Plaza in Oakland and Powell Street in Emeryville. Sensitivity is high (due primarily to the high level of use and very high liquefaction potential), while exposure is medium (due to inundation under the 16" + 100-yr SWEL and 55" + MHHW SLR scenarios). When combined with the lack of adequate alternate routes, this results in a high vulnerability rating. All considerations under consequence rate high, with the exception of socioeconomic impact (which is moderate because transit lines only pass through on this asset). The overall consequence is 4.67, making this a high-risk asset.	
Characteristics: • At grade or on elevated structures • Caltrans Lifeline route • Goods movement • Transit routes [AC Transit: C, F, FS, G, H, J, L, LA; Emery Go-Round, Amtrak Thruway] • Commuter route • Regional importance	

Sensitivity: High	
Year Built	Prior to 1964
Level of Use	
Peak Hour AADT AADTT	16,300 251,000 6,300
Seismic Retrofit	Temescal Creek Crossing; Bay Bridge HOV Separation; WB HOV - Toll Plaza Overcrossing
Annual O&M	$673,000
Liquefaction Susceptibility	Very High
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW 16" + 100-yr SWEL 16" + 100-yr SWEL + wind waves	0 ft 2 ft YES
55" + MHHW 55" + 100-yr SWEL 55" + 100-yr SWEL + wind waves	3 ft 5 ft YES
Inadequate Adaptive Capacity (16" SLR): High No adequate alternative	
Vulnerability Rating (mid century): High	



Projected Inundation with 16 inch SLR + 100-yr SWEL



Projected Inundation with 55 inch SLR + 100-yr SWEL

Consequence Rating (out of 5): 4.67	
Capital improvement cost	$45,087,000 (5)
Time to rebuild	84 months (bridge/elevated portions) (5)
Public safety	Caltrans Lifeline Highway, Emeryville Evacuation Route (5)
Economic impact - goods movement	6,300 AADTT (5)
Economic impact - commuter route	Freeway (and 7,826 daily transit riders) (5)
Socio-economic impact	Transit-Dependent area and pass-through transit (multiple lines) (3)
Risk Rating: High	

Shoreline Asset "Overtopping" Analysis	
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***
	30 ft
	55" + 100-yr SWEL
	30 ft
Length Overtopped (% of System)	***16" + 100-yr SWEL***
	10,510 ft (45%)
	55" + 100-yr SWEL
	16,900 ft (72%)
Average Depth of Overtopping	***16" + 100-yr SWEL***
	1.7 ft
	55" + 100-yr SWEL
	3.9 ft
System Responsible (See overview map)	2

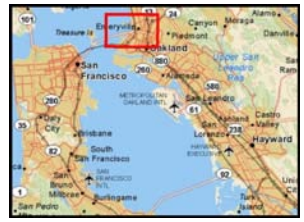
Future Projects
• Install Traffic Operations System • Install bicycle pedestrian path from Bay Bridge to West Grand Avenue • Reconstruct the Bay Bridge Maintenance Complex - South Yard • Construct Tow Services Building and Fueling Station at the Bay Bridge Toll Plaza area • Install median strip landscape planting at the Bay Bridge Toll Plaza area • Rehabilitate pavement between the Port of Oakland overcrossing and the Toll Plaza

Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL

Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

Interstate 880 (Oak St. to 23rd Ave.) (R-02a)



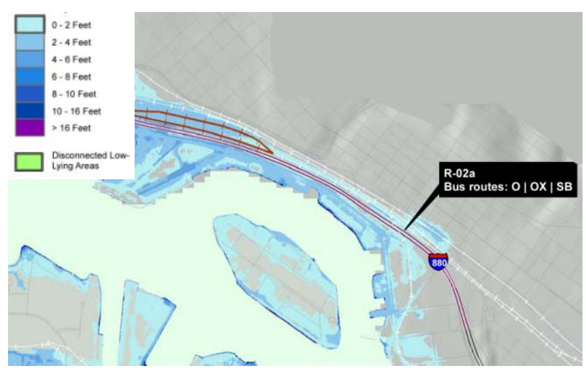
Asset Location / Jurisdiction
Oakland / FHWA, Caltrans

Summary
Interstate 880 (I-880) is a freeway that connects Alameda County to the greater region. The segment of I-880 between Oak Street and 23rd Avenue in Oakland is considered in this profile. Sensitivity is high (due primarily to the high level of use and very high liquefaction potential), while exposure is medium (due to inundation under the 16" + 100-yr SWEL and 55" + MHHW SLR scenarios). When combined with the availability of adequate alternate routes, this results in a medium vulnerability rating. Considerations under consequence rate high, with the exceptions of public safety (I-880 is not a Caltrans Lifeline Route) and socioeconomic impact (which is moderate because transit lines only pass through on this asset). The overall consequence is 4.33, making this a high-risk asset.

Characteristics:
- Goods movement
- Transit routes [AC Transit: S, SB]
- Commuter route
- Regional importance

Sensitivity: High	
Year Built	Prior to 1964
Level of Use	
Peak Hour	14,900
AADT	226,000
AADTT	24,182
Seismic Retrofit	5th Avenue Bridge retrofit to be completed by 2012
Annual O&M	$548,000
Liquefaction Susceptibility	Very High
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW	0 ft
16" + 100-yr SWEL	1 ft
16" + 100-yr SWEL + wind waves	YES
55" + MHHW	1 ft
55" + 100-yr SWEL	4 ft
55" + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16" SLR): Medium 7th Street/8th Street offer an alternate route, but provide inadequate capacity	
Vulnerability Rating (**mid century**)**: Medium**	

Projected Inundation with 16 inch SLR + 100-yr SWEL



Projected Inundation with 55 inch SLR + 100-yr SWEL

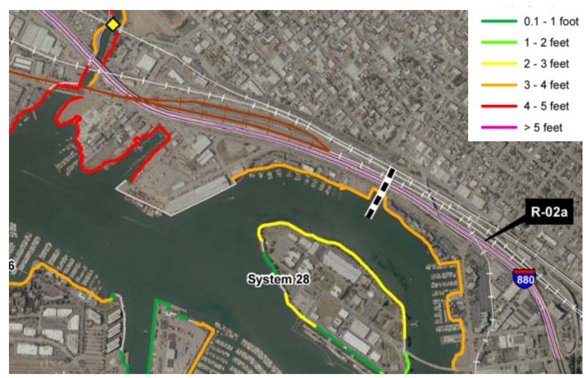
Consequence Rating (out of 5): 4.33	
Capital improvement cost	$100,474,000 (5)
Time to rebuild	84 months to rebuild 5th Ave bridge (5)
Public safety	Freeway (3)
Economic impact - goods movement	24,182 AADTT (5)
Economic impact - commuter route	Freeway (and 1,430 daily transit riders) (5)
Socio-economic impact	Communities of Concern + Transit Dependent area; Pass-through transit (multiple lines) (3)
Risk Rating: High	

Shoreline Asset "Overtopping" Analysis	
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***
	80 ft
	55" + 100-yr SWEL
	80 ft
Length Overtopped (% of System)	***16" + 100-yr SWEL***
	7,950 ft (26%)
	55" + 100-yr SWEL
	24,070 ft (80%)
Average Depth of Overtopping	***16" + 100-yr SWEL***
	1.4 ft
	55" + 100-yr SWEL
	3.2 ft
System Responsible (See overview map)	4, 5 System 3 contributes a negligible amount of inundation along the Lake Merritt Channel.

Future Projects

- I-880 at 23rd/29th Avenue interchange safety and access improvements
- Roadway rehabilitation between 5th Avenue and 23rd Avenue
- Install concrete barrier between 16th Avenue overcrossing and 23rd Avenue overcrossing
- Relocate bridge across the Lake Merritt Channel, along the UPRR tracks

Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

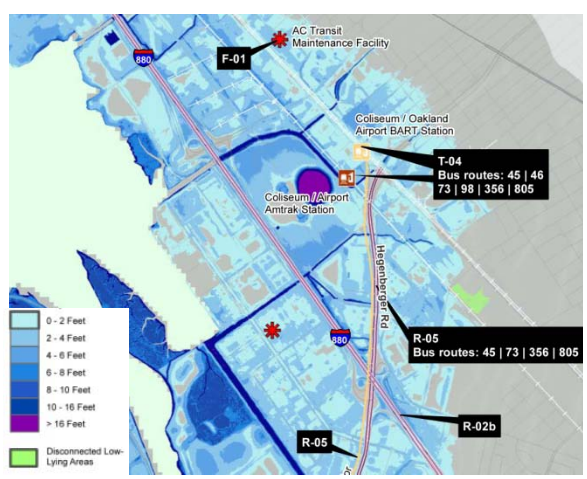
Asset Risk Profile

Interstate 880 (High St. to 98th Ave.) (R-02b)

Asset Location / Jurisdiction Oakland / FHWA, Caltrans
Summary Interstate 880 (I-880) is a freeway that connects Alameda County to the greater region. The segment of I-880 between High Street and 98th Avenue in Oakland is considered in this profile. Sensitivity is high (due primarily to the high level of use and very high liquefaction potential), while exposure is medium (due to inundation under the 16" + 100-yr SWEL and 55" + MHHW SLR scenarios). When combined with the availability of adequate alternate routes, this results in a medium vulnerability rating. Considerations under consequence rate medium to high, resulting in an overall consequence of 4.00 and making this a high-risk asset.
Characteristics: • Goods movement • Transit routes [AC Transit: OX, S, SB] • Commuter route • Regional importance

Sensitivity: Medium	
Year Built	Significant changes in 1968/1970
Level of Use	
Peak Hour	14,000
AADT	212,000
AADTT	16,197
Seismic Retrofit	High Street Bridge not retrofitted
Annual O&M	$677,000
Liquefaction Susceptibility	Very High, Medium
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW	0 ft
16" + 100-yr SWEL	2 ft
16" + 100-yr SWEL + wind waves	YES
55" + MHHW	3 ft
55" + 100-yr SWEL	5 ft
55" + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16" SLR): Medium San Leandro Street provides an alternate route	
Vulnerability Rating (mid century): Medium	

Projected Inundation with 16 inch SLR + 100-yr SWEL



Projected Inundation with 55 inch SLR + 100-yr SWEL

Consequence Rating (out of 5): 4.00	
Capital improvement cost	$50.9 million ($22.3 million for roadway section and $28.6 million for High Street Bridge) (5)
Time to rebuild	84 months to rebuild High Street bridge (5)
Public safety	Freeway (3)
Economic impact - goods movement	16,197 AADTT (5)
Economic impact - commuter route	Freeway (and 768 daily transit riders) (5)
Socio-economic impact	Transit Dependent area and pass-through transit (multiple lines) (3)
Risk Rating: High	

Shoreline Asset “Overtopping” Analysis	
Proximity to Overtopping (distance)	***16” + 100-yr SWEL***
	60 ft
	55” + 100-yr SWEL
	0 ft
Length Overtopped (% of System)	***16” + 100-yr SWEL***
	14,570 ft (27%)
	55” + 100-yr SWEL
	49,930 ft (92%)
Average Depth of Overtopping	***16” + 100-yr SWEL***
	1.2 ft
	55” + 100-yr SWEL
	3.2 ft
System Responsible (See overview map)	5, 6, 10

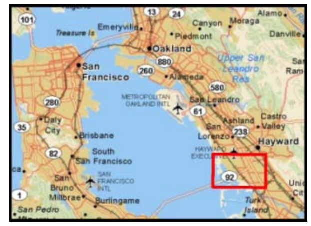
Future Projects
• Widen to accommodate southbound HOV lane from Hegenberger Road to 98th Avenue • Bridge deck resurfacing and resealing • Accommodations for BART Oakland Airport Connector

Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL

Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

State Route (SR) 92 (R-03)

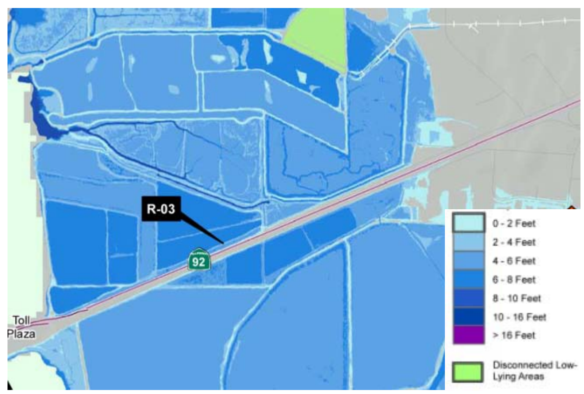


Asset Location / Jurisdiction
Hayward / Caltrans

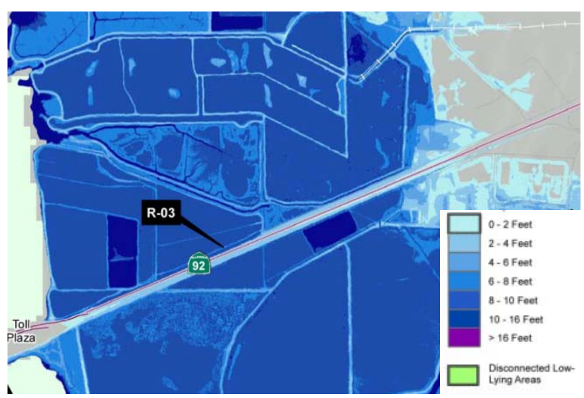
Summary
State Route (SR) 92 is a freeway that connects Alameda County to the greater region. The segment of SR 92 between the San Mateo Bridge toll plaza and Clawiter Road in Hayward is considered in this profile. Sensitivity is low due to moderate level of use and operations and maintenance costs and medium liquefaction potential, while exposure is medium (due to inundation under the 55" + 100-yr SWEL SLR scenario). When combined with the lack of adequate alternate routes, this results in a medium vulnerability rating. Considerations under consequence rate medium to low, with the exception of economic impact – commuter route (rated high because SR 92 is a freeway), resulting in an overall consequence of 2.67, and making this a medium-risk asset.

Characteristics:
- Goods movement
- Transit routes [AC Transit: M]
- Commuter route
- Regional importance

Sensitivity: Low	
Year Built	Significant changes in 1967
Level of Use	
Peak Hour	7,800
AADT	86,000
AADTT	1,806
Seismic Retrofit	At grade, not applicable
Annual O&M	$436,000
Liquefaction Susceptibility	Medium
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW	0 ft
16" + 100-yr SWEL	0 ft
16" + 100-yr SWEL + wind waves	YES
55" + MHHW	0 ft
55" + 100-yr SWEL	3 ft
55" + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16" SLR): High No adequate alternative	
Vulnerability Rating (mid century): Medium	



Projected Inundation with 16 inch SLR + 100-yr SWEL



Projected Inundation with 55 inch SLR + 100-yr SWEL

Consequence Rating (out of 5): 2.67	
Capital improvement cost	$13.2 million (1)
Time to rebuild	60 months (3)
Public safety	Freeway (3)
Economic impact - goods movement	1,806 AADTT (3)
Economic impact - commuter route	Freeway (and 491 daily transit riders) (5)
Socio-economic impact	Pass-through transit (1)
Risk Rating: Medium	

Shoreline Asset "Overtopping" Analysis	
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***
	70 ft
	55" + 100-yr SWEL
	0 ft
Length Overtopped (% of System)	***16" + 100-yr SWEL***
	34,790 ft (26%)
	55" + 100-yr SWEL
	125,270 ft (93%)
Average Depth of Overtopping	***16" + 100-yr SWEL***
	1.6 ft
	55" + 100-yr SWEL
	3.2 ft
System Responsible (See overview map)	23, 24

Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL

Future Projects
• SR 92/Clawiter Road/Whitesell Street interchange improvements and local intersection improvements • Non-capacity increasing freeway/expressway interchange modifications • Install ramp metering • Install Fiber Optic Communication

Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

West Grand Avenue (R-04)

Asset Location / Jurisdiction
Oakland / City of Oakland
Summary West Grand Avenue is an arterial that connects between Broadway and I-80 in Oakland. This profile considers the segment between Adeline Street and I-80. Sensitivity is high (due to the high level of use and very high liquefaction potential), while exposure to inunadation is medium (due to inundation under the 55" + MHHW SLR scenario). Maritime Street/7th Street could provide an alternate route, resulting in a medium rating of overall vulnerability. Consequence rates moderate for all criteria except goods movement, which is high (given the asset’s link to I-80 and I-880). The overall consequence rating is 3.00, making this a medium-risk asset.
Characteristics: • At-grade, elevated • Oakland Evacuation Route • Goods movement • Transit routes [AC Transit: NL] • Bike route

Sensitivity: High	
Remaining Service Life	51 years
Level of Use	
ADT	22,912
Seismic Retrofit	Elevated structures built to post-Loma Prieta seismic standards
Annual O&M	$2.05 million (30 years)
Liquefaction Suceptibility	Very high
Exposure: Medium	
Maximum Inundation Depths	
16” + MHHW 16” + 100-yr SWEL 16” + 100-yr SWEL + wind waves	0 ft 0 ft YES
55” + MHHW 55” + 100-yr SWEL 55” + 100-yr SWEL + wind waves	3 ft 5 ft YES
Inadequate Adaptive Capacity (16” SLR): Medium Maritime Street/7th Street could provide an alternate route	
Vulnerability Rating (**mid century**): **Medium**	

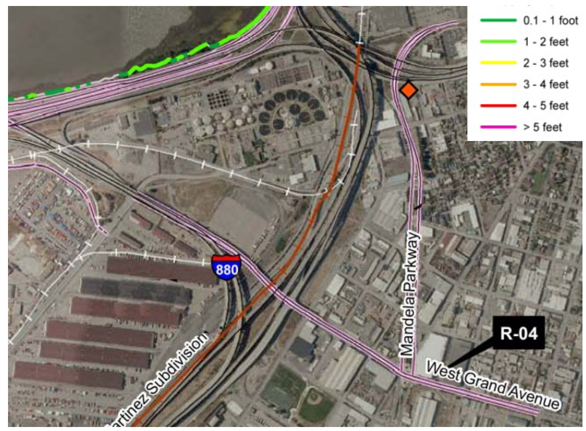
Projected Inundation with 16 inch SLR + 100-yr SWEL

Projected Inundation with 55 inch SLR + 100-yr SWEL

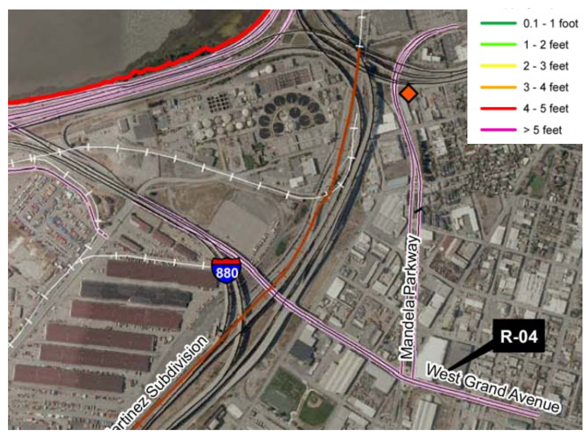
Consequence Rating (out of 5): 3.00	
Capital improvement cost	$22.4 million for portion between Wood and Adeline Streets (3)
Time to rebuild	2 years for portion between Wood and Adeline Streets (1)
Public safety	Oakland Evacuation Route (3)
Economic impact - goods movement	Connects Port of Oakland (seaport) to freeway network (5)
Economic impact - commuter route	2,320 daily transit riders (3)
Socio-economic impact	Transit-Dependent area and local transit access (3)
Risk Rating: Medium	

Shoreline Asset "Overtopping" Analysis		
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***	330 ft
	55" + 100-yr SWEL	330 ft
Length Overtopped (% of System)	***16" + 100-yr SWEL***	10,510 ft (45%)
	55" + 100-yr SWEL	16,900 ft (72%)
Average Depth of Overtopping	***16" + 100-yr SWEL***	1.7 ft
	55" + 100-yr SWEL	3.9 ft
System Responsible (See overview map)	2 Asset is landward of System 3, but shoreline overtopping does not contribute to inundation of asset	

Future Projects
None



Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

Hegenberger Road, Airport Drive and Future Oakland Airport BART Connector (R-05)

Asset Location / Jurisdiction
Oakland / City of Oakland, Port of Oakland, BART

Summary

Hegenberger Road and Airport Drive are arterials that connect between Oakland International Airport, SR 61, and I-880 in Oakland. Both assets have medium sensitivity (due primarily to very high liquefaction potential) and exposure (due to inundation under the 16" + 100-yr SWEL and 55" + MHHW SLR scenarios). 98th Avenue is an alternate route to Hegenberger Road, which rates medium for vulnerability; however, no adequate alternative exists for Airport Drive, making its vulnerability medium-high. For Hegenberger Road, consequence rates high for capital improvement cost, goods movement, and socioeconomic impacts, while public safety is moderate, and time to rebuild is low. For Airport Drive, consequence rates high for goods movement and socioeconomic impacts, and moderate for all other considerations. The overall consequence rating is 3.67 for Hegenberger Road and 3.33 for Airport Drive, making both medium-risk assets.

The BART Oakland Airport Connector is a future automated guideway transit line currently under construction between the Coliseum / Oakland Airport BART Station and Oakland International Airport. The line will operate on an elevated structure along Hegenberger Road and Airport Drive. Sensitivity cannot be rated because the asset has not yet been built, while exposure is rated medium, corresponding to Hegenberger Road and Airport Drive, as noted above. A replacement bus service could operate on Hegenberger Road as it does currently, resulting in a medium vulnerability rating for this asset. Consequence is rated high for capital improvement costs and socioeconomic impact, moderate for time to rebuild and commuter use, and low for public safety and goods movement, which does not apply. The overall consequence rating is 3.00, making this a medium-risk asset.

Characteristics:	***Hegenberger Road***	***Airport Drive***	***Future Oakland Airport BART Connector***
	• Oakland Evacuation Route • Goods movement • Transit routes [AC Transit: 45, 73, 356, 805] • Bike route • Regional importance	• Subgrade at Doolittle Drive (SR 61) • Oakland Evacuation Route • Goods movement • Transit routes [AC Transit: 73, 805] • Bike route • Regional importance	• Elevated • Transit routes [1 BART line]

	Hegenberger Road	**Airport Drive**	**Future Oakland Airport BART Connector**
Sensitivity:	**Medium**	**Medium**	**N/A**
Remaining Service Life	51 years	Data unavailable in project timeframe	Under construction, operation expected in 2014
Level of Use	18,000 (AADT)	Data unavailable in project timeframe	10,000 daily transit riders (2020 estimate)
Seismic Retrofit	Data unavailable in project timeframe		N/A
O&M	$6,257,000 (30 years)	Data unavailable in project timeframe	
Liquefaction Susceptibility	Very High	Very High	Very High
Exposure:	**Medium**	**Medium**	**Medium**
Maximum Inundation Depth			
16” + MHHW	0 ft	0 ft	0 ft
16” + 100-yr SWEL	2 ft	26 ft*	8 ft
16” + 100-yr SWEL + wind waves	YES	YES	YES
55” + MHHW	3 ft	27 ft*	8 ft
55” + 100-yr SWEL	5 ft	29 ft*	11 ft
55” + 100-yr SWEL + wind waves	YES	YES	YES
Inadequate Adaptive Capacity (16” SLR):	Medium, 98th Avenue is an alternate route	High, no adequate alternative	Replacement bus service could operate as AirBART does on Hegenberger Road
Vulnerability Rating (midcentury):	**Medium**	**Medium-High**	**Medium**

*High inundation depth is due to below-grade road segment

	Hegenberger Road	Airport Drive	Future Oakland Airport BART Connector
Consequence Rating (out of 5):	**3.67**	**3.33**	**3.00**
Capital improvement cost	$85,148,000 (5)	Professional judgment (includes underpass/overpass structures) (3)	$484 million (5)
Time to rebuild	2 years (1)		5-year construction schedule (3)
Public safety	Oakland Evacuation Route (3)		Minor consequence (1)
Economic impact - goods movement	Connects Port of Oakland (air freight) to freeway network (5)		Not applicable (1)
Economic impact - commuter route	5,509 daily transit riders (3)	2,972 daily transit riders (3)	10,000 daily transit riders (2020 estimate) (3)
Socio-economic impact	Community of Concern + Transit Dependent area; local transit (multiple lines) (5)		
Risk Rating:	**Medium**	**Medium**	**Medium**

Shoreline Asset "Overtopping" Analysis			
	Hegenberger Road	**Airport Drive**	**Future Oakland Airport BART Connector**
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***		
	100 ft	same	same
	55" + 100-yr SWEL		
	0 ft	same	same
Length Overtopped (% of System)	***16" + 100-yr SWEL***		
	11,330 ft (17%)	same	same
	55" + 100-yr SWEL		
	53,820 ft (79%)	same	same
Average Depth of Overtopping	***16" + 100-yr SWEL***		
	1 ft	same	same
	55" + 100-yr SWEL		
	2.9 ft	same	same
System Responsible (See overview map)	8, 9, 10, 11	same	same

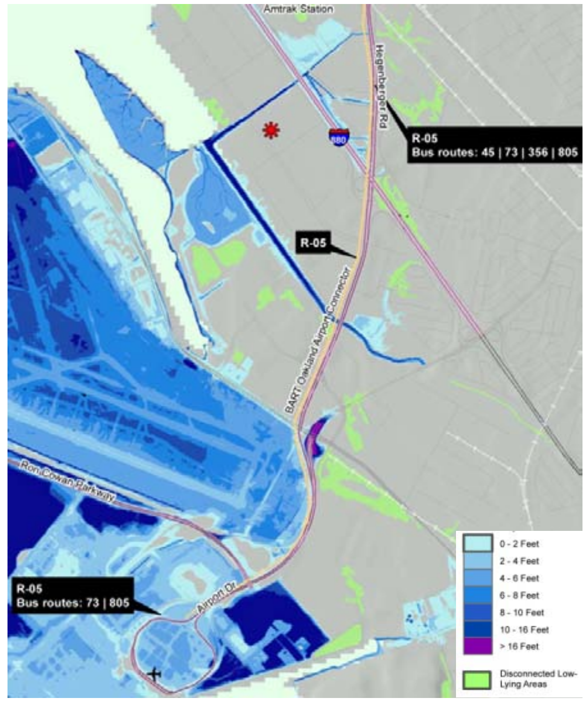
Future Projects	
None	Currently under construction

Asset Risk Profile

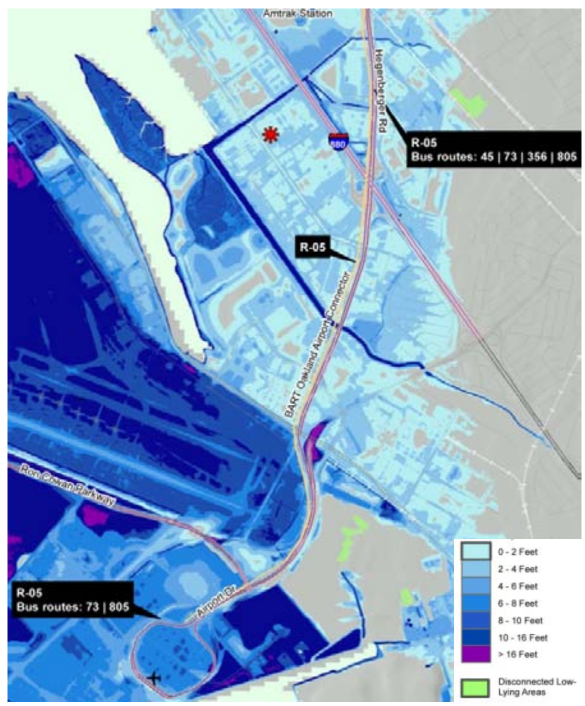
Hegenberger Road

Airport Drive

Future Oakland Airport BART Connector



Projected Inundation Depth at 16 inch SLR + 100-yr SWEL



Projected Inundation Depth at 55 inch SLR + 100-yr SWEL

Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL

Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

Powell Street (R-06)

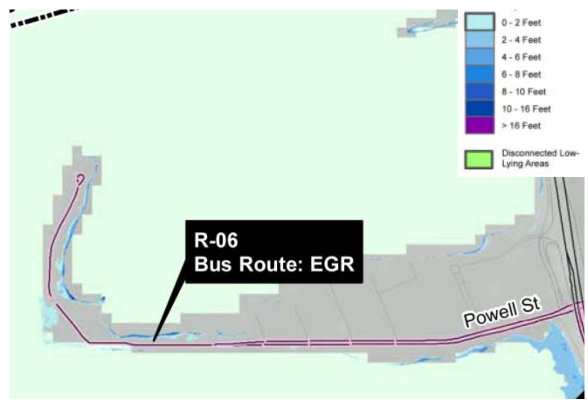
Asset Location / Jurisdiction
Emeryville / City of Emeryville

Summary
Powell Street connects between San Pablo Avenue and Marina Park in Emeryville, and has an interchange with I-80/I-580. This profile considers the segment of Powell Street west of I-80/I-580. Sensitivity is high (due to its relatively high level of use and very high liquefaction potential), while exposure is medium (due to inundation under the 55" + MHHW SLR scenario). When combined with the lack of adequate alternate routes, this results in a high vulnerability rating. Consequence rates low for all but Powell Street's role as a commuter route, which is moderate, given its relatively low level of transit ridership. The overall consequence rating is 1.33, making this a low-risk asset.

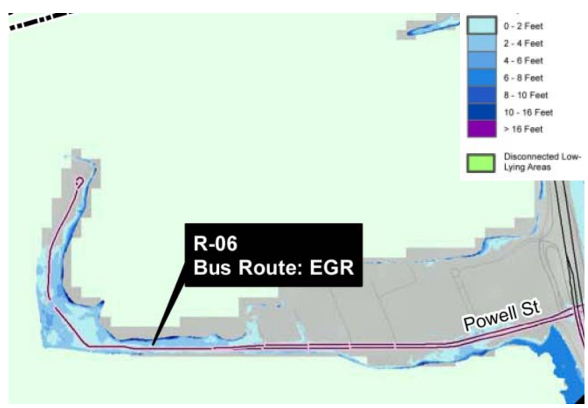
Characteristics:

- Transit routes [Emery Go-Round]
- Bike route

Sensitivity: High	
Year Built	1973
Level of Use	
Peak Hour	2,652
ADT	26,520
Seismic Retrofit	Not applicable
Annual O&M	$40,000
Liquefaction Susceptibility	Very high
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW	0 ft
16" + 100-yr SWEL	0 ft
16" + 100-yr SWEL + wind waves	YES
55" + MHHW	1 ft
55" + 100-yr SWEL	3 ft
55" + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16" SLR): High	
No adequate alternative	
Vulnerability Rating (mid century): High	



Projected Inundation with 16 inch SLR + 100-yr SWEL



Consequence Rating (out of 5): 1.33	
Capital improvement cost	$15 million (paving, storm drain, lights, underground power lines) (1)
Time to rebuild	2 years (1)
Public safety	Local street; however, provides fire station access (1)
Economic impact - goods movement	Local street (1)
Economic impact - commuter route	3,500 daily transit riders (3)
Socio-economic impact	Local transit access only (1)
Risk Rating: Low	

Shoreline Asset “Overtopping” Analysis		
Proximity to Overtopping (distance)	***16” + 100-yr SWEL***	50 ft
	55” + 100-yr SWEL	30 ft
Length Overtopped (% of System)	***16” + 100-yr SWEL***	1,910 ft (9%)
	55” + 100-yr SWEL	11,360 ft (52%)
Average Depth of Overtopping	***16” + 100-yr SWEL***	1.5 ft
	55” + 100-yr SWEL	2.8 ft
System Responsible (See overview map)	1	

Future Projects
None

Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL

Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

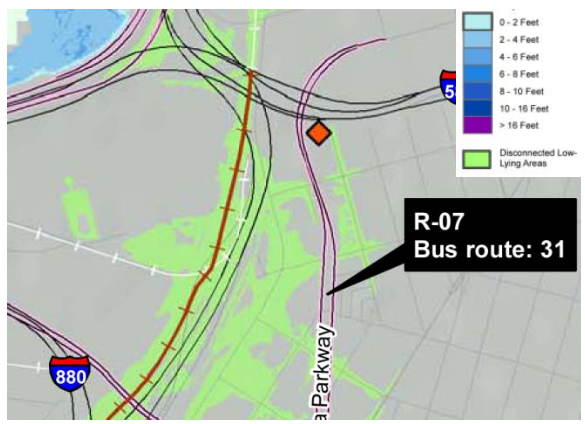
Mandela Parkway (R-07)

Asset Location / Jurisdiction
Oakland / City of Oakland

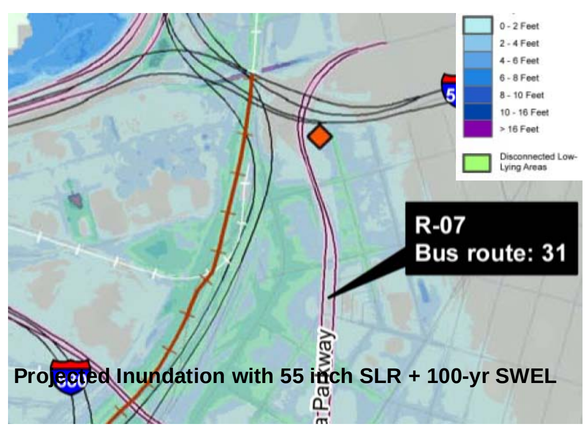
Summary
Mandela Parkway is a collector street that runs between 3rd Street in Oakland to the Emeryville border. This profile considers the segment north of West Grand Avenue. Sensitivity is low (due to the relatively low level of use and annual O&M cost), while exposure is medium due to inundation under the 55" + 100-yr SWEL SLR scenario. When combined with the fact that Peralta Street provides an alternate route, this results in a medium vulnerability rating. Consequence rates low for all but Mandela Parkway's role as a commuter route and socioeconomic impact, which are moderate, given the connection to freeways, Community of Concern, and Transit-Dependent populations. The overall consequence rating is 1.67, making this a low-risk asset.

Characteristics:
- Transit routes [31]
- Bike route

Sensitivity: Low	
Remaining Service Life	40 years
Level of Use	
ADT	8,030
Seismic Retrofit	Not applicable
O&M	$972,000 (30 years)
Liquefaction Suceptibility	Very high
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW	0 ft
16" + 100-yr SWEL	0 ft
16" + 100-yr SWEL + wind waves	YES
55" + MHHW	2 ft
55" + 100-yr SWEL	4 ft
55" + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16" SLR): Medium Peralta Street provides an alternate route	
Vulnerability Rating (**mid century**)**: Medium**	



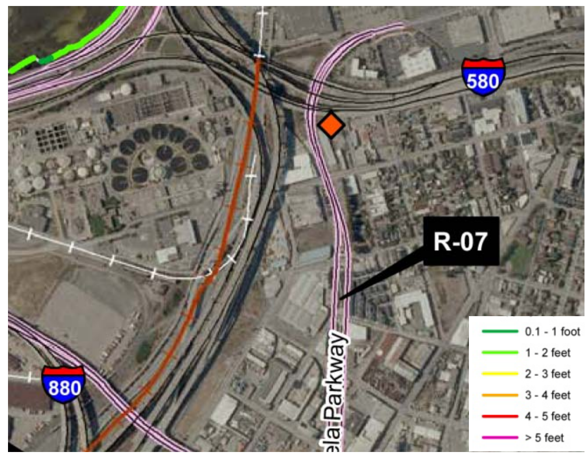
Projected Inundation with 16 inch SLR + 100-yr SWEL



Projected Inundation with 55 inch SLR + 100-yr SWEL

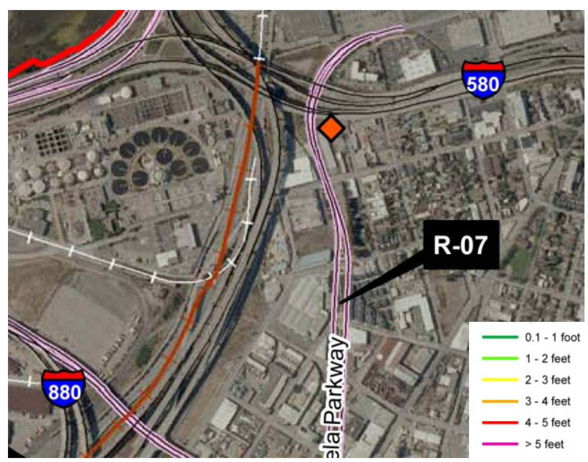
Consequence Rating (out of 5): 1.67	
Capital improvement cost	$15.9 million (between West Grand Avenue and 32nd Street) (1)
Time to rebuild	2 years (between West Grand Avenue and 32nd Street) (1)
Public safety	Not applicable (1)
Economic impact - goods movement	Local street (1)
Economic impact - commuter route	1,700 daily transit riders (3)
Socio-economic impact	Community of Concern + Transit Dependent area and local transit access (3)
Risk Rating: Low	

Shoreline Asset “Overtopping” Analysis	
Proximity to Overtopping (distance)	***16” + 100-yr SWEL***
	1,670 ft
	55” + 100-yr SWEL
	1,650 ft
Length Overtopped (% of System)	***16” + 100-yr SWEL***
	10,510 ft (45%)
	55” + 100-yr SWEL
	16,900 ft (72%)
Average Depth of Overtopping	***16” + 100-yr SWEL***
	1.7 ft
	55” + 100-yr SWEL
	3.9 ft
System Responsible (See overview map)	2 Asset is landward of System 3, but shoreline overtopping does not contribute to inundation of asset.



Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL

Future Projects
None



Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

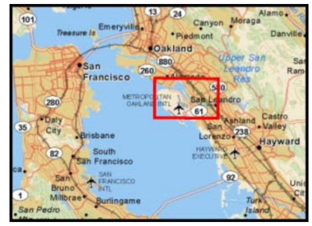
Asset Risk Profile

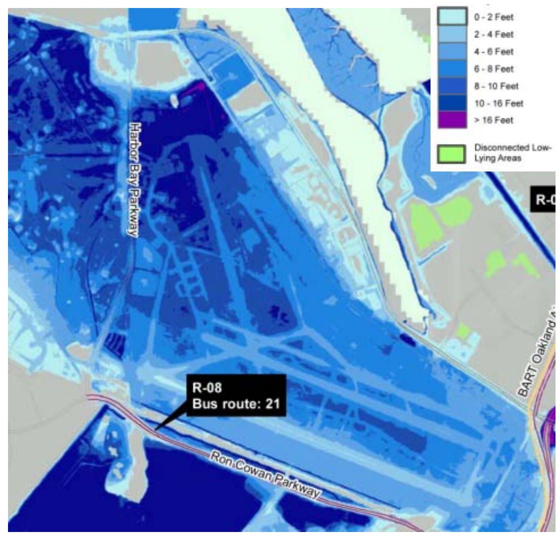
Ron Cowan Parkway (R-08)

Asset Location / Jurisdiction
Oakland / Port of Oakland
Summary Ron Cowan Parkway is a collector street that connects Bay Farm Island in Alameda with the Oakland International Airport. Sensitivity is high (due to very high liquefaction potential), as is exposure (due to inundation under the 16" + MHHW SLR scenario). Harbor Bay Parkway/Doolittle Drive provides an alternate route, but would likely be similarly affected by inundation, resulting in a high vulnerability rating. Consequence rates moderate for nearly all considerations except goods movement, which is high (given that the street is connected to the airport), and public safety, which is low. The overall consequence rating is 3.00, making this a medium-risk asset.
Characteristics: • Transit routes [AC Transit: 21] • Bike route

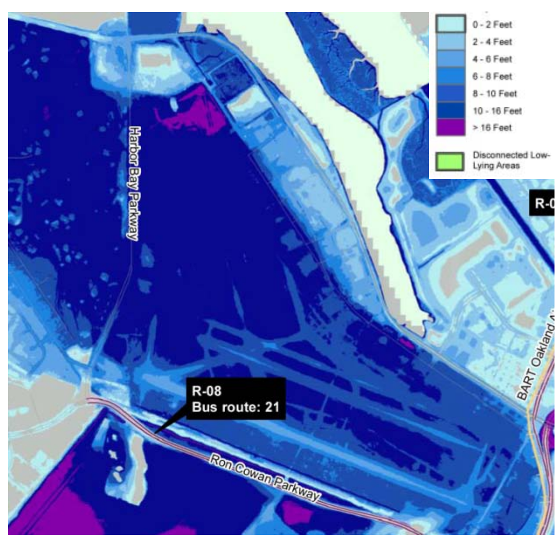
Sensitivity: High	
Data unavailable in project timeframe.	
Liquefaction Susceptibility	Very high
Exposure: High	
Maximum Inundation Depths	
16" + MHHW	15 ft*
16" + 100-yr SWEL	19 ft*
16" + 100-yr SWEL + wind waves	YES
55" + MHHW	19 ft*
55" + 100-yr SWEL	22 ft*
55" + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16" SLR): High Harbor Bay Parkway/Doolittle Drive provide an alternate route, but would likely be similarly affected by inundation.	
Vulnerability Rating (**mid century**)**: High**	

* High inundation depth is due to below-grade road segment





Projected Inundation with 16 inch SLR + 100-yr SWEL

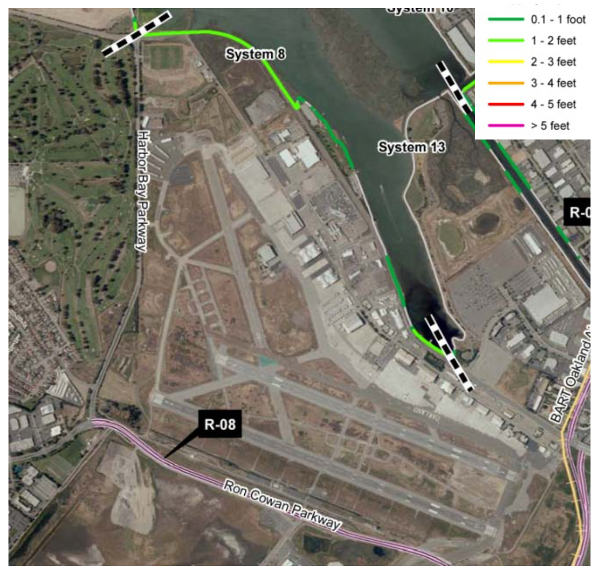


Projected Inundation with 55 inch SLR + 100-yr SWEL

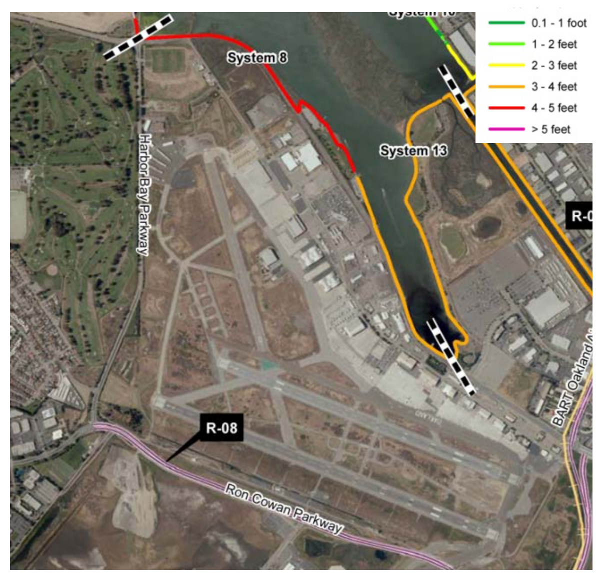
Consequence Rating (out of 5): 3.00	
Capital improvement cost	Data unavailable; professional judgment (includes an underpass) (3)
Time to rebuild	Data unavailable; professional judgment (includes an underpass) (3)
Public safety	Not applicable (1)
Economic impact - goods movement	Connects Port of Oakland (air freight) to freeway network (5)
Economic impact - commuter route	2,064 daily transit riders (3)
Socio-economic impact	Transit Dependent area; local transit access (3)
Risk Rating: Medium	

Shoreline Asset "Overtopping" Analysis		
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***	3,290 ft
	55" + 100-yr SWEL	1,880 ft
Length Overtopped (% of System)	***16" + 100-yr SWEL***	6,460 ft (19%)
	55" + 100-yr SWEL	21,630 ft (63%)
Average Depth of Overtopping	***16" + 100-yr SWEL***	1.2 ft
	55" + 100-yr SWEL	2.7 ft
System Responsible (See overview map)	8, 11 System 8 responsible for inundation at 16" SLR. Systems 8 & 11 responsible for inundation at 55" SLR.	

Future Projects
None



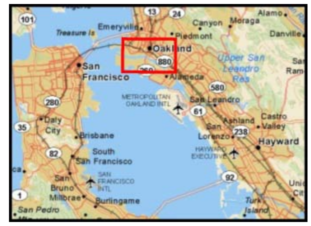
Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

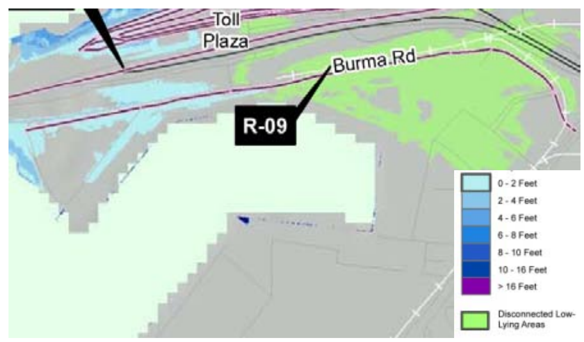
Asset Risk Profile

Burma Road (R-09)

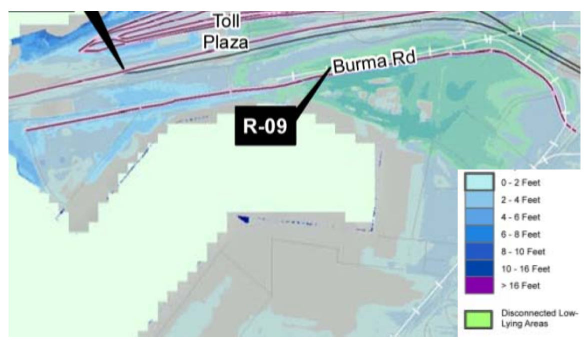


Asset Location / Jurisdiction Oakland / Port of Oakland	
Summary Burma Road is a local street that parallels I-80 within the Port of Oakland. Sensitivity is high (due to very high liquefaction potential), while inundation exposure is medium (due to inundation under the 55" + MHHW SLR scenario). When combined with the lack of adequate alternate routes, this results in a medium-high vulnerability rating. Consequence rates low for all considerations except goods movement, which is high, given the street's function within the Port of Oakland. The overall consequence rating is 1.67, making this a low-risk asset.	
Characteristics: • Goods movement • Bike route	

Sensitivity: High	
Data unavailable in project timeframe.	
Liquefaction Susceptibility	Very high
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW	0 ft
16" + 100-yr SWEL	1 ft
16" + 100-yr SWEL + wind waves	YES
55" + MHHW	4 ft
55" + 100-yr SWEL	6 ft
55" + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16" SLR): High No adequate alternative	
Vulnerability Rating (mid century): Medium-High	



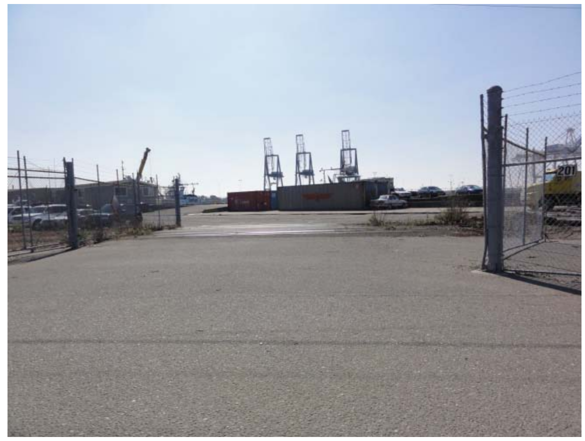
Projected Inundation with 16 inch SLR + 100-yr SWEL

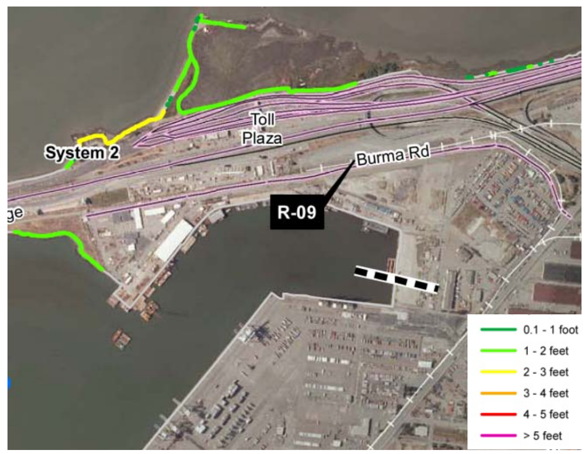


Consequence Rating (out of 5): 1.67	
Capital improvement cost	Data unavailable; professional judgment (local street at grade) (1)
Time to rebuild	Data unavailable; professional judgment (local street at grade) (1)
Public safety	Not applicable (1)
Economic impact - goods movement	Connects Port of Oakland (seaport) to freeway network) (5)
Economic impact - commuter route	Not used by transit vehicles (1)
Socio-economic impact	Transit Dependent area only (1)
Risk Rating: Low	

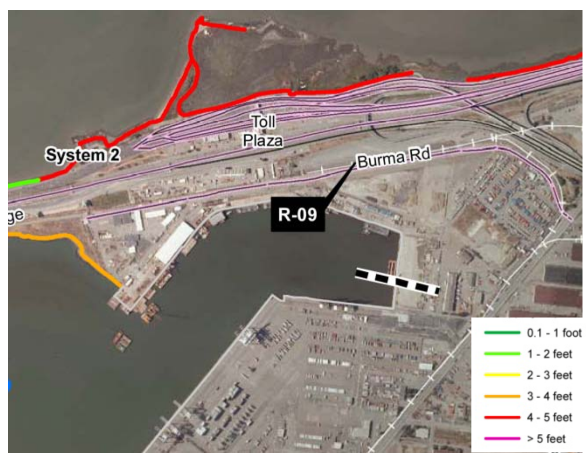
Shoreline Asset "Overtopping" Analysis	
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***
	400ft
	55" + 100-yr SWEL
	400ft
Length Overtopped (% of System)	***16" + 100-yr SWEL***
	10,510 ft (45%)
	55" + 100-yr SWEL
	16,900 ft (72%)
Average Depth of Overtopping	***16" + 100-yr SWEL***
	1.7 ft
	55" + 100-yr SWEL
	3.9 ft
System Responsible (See overview map)	2

Future Projects
Burma Road will provide the primary access for new development on the southern Bay Bridge peninsula, which will include a museum, regional park, commercial and other uses. This project is set to begin in 2015 following completion of the new span and removal of the old span.





Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

Cabot Boulevard (R-10)

Asset Location / Jurisdction
Hayward / City of Hayward

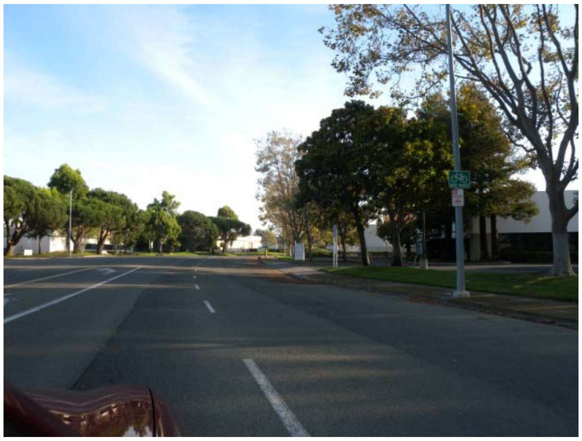
Summary
Cabot Boulevard is a local street in the industrial area near the Hayward shoreline. In the future, an extension of the street and interchange with SR 92 are planned. Sensitivity is low (due to relatively low level of use and annual O&M cost, and medium liquefaction potential), while inundation exposure is medium (due to inundation under the 55" + MHHW SLR). When combined with the fact that Winton Avenue/Depot Road/Clawiter Road would provide alternate routes, this results in a low vulnerability rating. Consequence rates high for capital improvement cost (nearly $65 million); moderate for time to build, the asset's role as a commuter route, and socioeconomic impact; and low for public safety and goods movement. The overall consequence rating is 2.67, making this a medium-risk asset.

Characteristics:
- Transit route [AC Transit: 86]
- Bike route

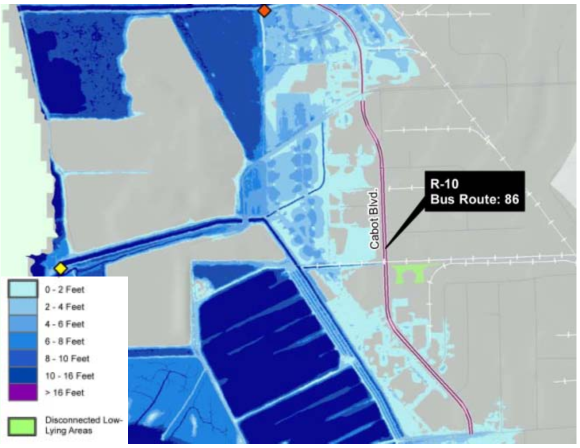
Sensitivity: Low	
Remaining Service Life	25 years
Level of Use	
ADT	524
Seismic Retrofit	Not applicable
O&M	$2.3 million (30 years)
Liquefaction Susceptibility	Medium
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW	0 ft
16" + 100-yr SWEL	0 ft
16" + 100-yr SWEL + wind waves	YES
55" + MHHW	2 ft
55" + 100-yr SWEL	4 ft
55" + 100-yr SWEL + wind waves	YES

Inadequate Adaptive Capacity (16" SLR): Low
Winton Avenue/Depot Road/Clawiter Road provide alternate routes

Vulnerability Rating (**mid century**)**: Low**



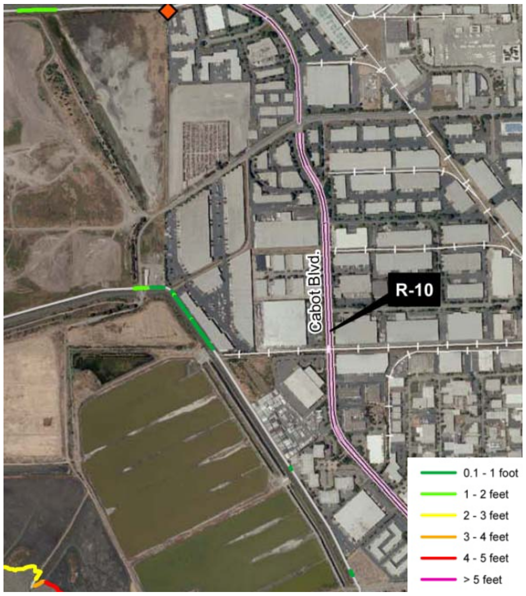
Projected Inundation with 16 inch SLR + 100-yr SWEL



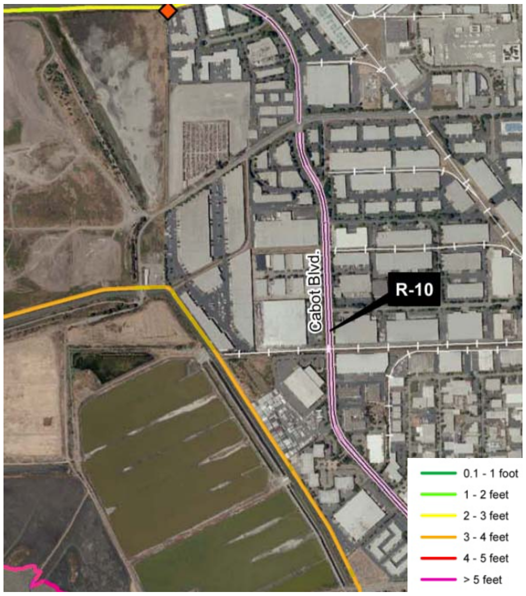
Consequence Rating (out of 5): 2.67	
Capital improvement cost	$64.7 million (5)
Time to rebuild	2+ years (includes proposed interchange) (3)
Public safety	Not applicable (1)
Economic impact - goods movement	Local street (1)
Economic impact - commuter route	946 daily transit riders (3)
Socio-economic impact	Community of Concern; local transit access (3)
Risk Rating: Medium	

Shoreline Asset "Overtopping" Analysis	
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***
	70 ft
	55" + 100-yr SWEL
	0 ft
Length Overtopped (% of System)	***16" + 100-yr SWEL***
	12,160 ft (30%)
	55" + 100-yr SWEL
	39,030 ft (98%)
Average Depth of Overtopping	***16" + 100-yr SWEL***
	2.2 ft
	55" + 100-yr SWEL
	3.7 ft
System Responsible (See overview map)	23

Future Projects
Extension to and interchange with SR 92



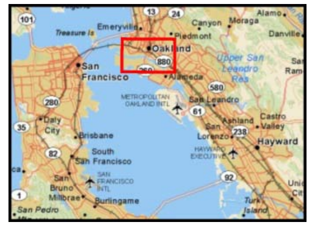
Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

Webster and Posey Tubes (R-11)



Asset Location / Jurisdiction
Oakland – Alameda / Caltrans

Summary
The Webster and Posey Tubes are underwater tunnels that connect Alameda and Oakland and compose State Route 260, though they are signed as State Route 61. Both assets rank medium for sensitivity. Exposure for Webster Tube is medium (due to inundation under both the 16" + 100-yr SWEL and 55" + MHHW SLR scenarios) and high for Posey Tube (due to inundation under the 16" + MHHW SLR scenario). Bridges connecting Alameda with Oakland provide alternate routes, giving both medium vulnerability ratings. Consequence rates high for capital improvement cost and time to rebuild, as well as the tubes' role as commuter routes. Ratings for public safety, goods movement, and socioeconomic impacts are all moderate, since the tubes provide evacuation routes and serve multiple transit routes. The overall consequence rating is 4.00 for both the Webster and Posey Tubes, making them high-risk assets.

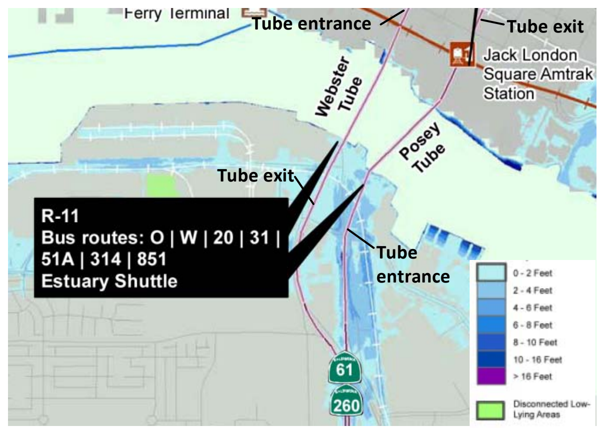
Characteristics:

- Commuter Route
- Goods movement
- Transit Routes [AC Transit: O, W, 20, 31, 51A, 314, 851; Estuary Shuttle]

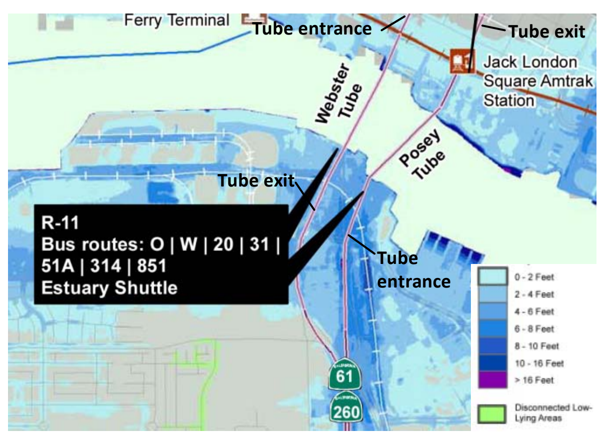
	Posey Tube	Webster Tube
Sensitivity:	**Medium**	**Medium**
Year Built	1927	1963
Level of Use		
Peak Hour	1,850	1,850
AADT	22,300	22,300
AADTT	535	535
Seismic Retrofit	Yes (2004; liquefaction potential was accounted for)	Yes (2005; liquefaction potential was accounted for)
Annual O&M	$83,300	$72,800
Liquefaction Suceptibility	Very High	Very High
Exposure:	**High**	**Medium**
Maximum Inundation Depths*		
16" + MHHW	4 ft	0 ft
16" + 100-yr SWEL	22 ft	22 ft
16" + 100-yr SWEL + wind waves	YES	YES
55" + MHHW	23 ft	23 ft
55" + 100-yr SWEL	25 ft	25 ft
55" + 100-yr SWEL + wind waves	YES	YES
Inadequate Adaptive Capacity (16" SLR): Park Street, Fruitvale and High Street Bridges provide alternate routes		
Vulnerability Rating (**mid century**)**: High**		

*Depths due to tunnels filling with water entering at the portals

Webster Tube



Projected Inundation with 16 inch SLR + 100-yr SWEL



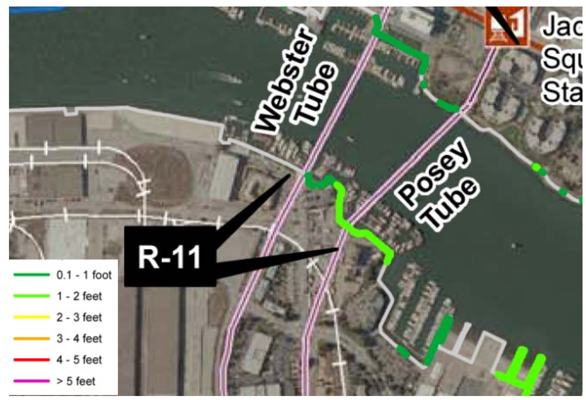
Projected Inundation with 55 inch SLR + 100-yr SWEL

Consequence Rating (out of 5): 4.0	
Capital improvement cost	Replacement cost: $360,000,000 (for both tubes) (5)
Time to rebuild	Seismic retrofit took about 8 years; rebuild would take at least as long (5)
Public safety	Alameda evacuation route (3)
Economic impact - goods movement	535 AADTT (3)
Economic impact - commuter route	18,333 daily transit riders (5)
Socio-economic impact	MTC Communities of Concern and pass-through transit (multiple lines) (3)
Risk Rating: High	

Shoreline Asset “Overtopping” Analysis		
	Posey Tube	**Webster Tube**
Proximity to Overtopping (distance)	***16” + 100-yr SWEL***	
	650 ft	950 ft
	55” + 100-yr SWEL	
	530 ft	940 ft
Length Overtopped (% of System)	***16” + 100-yr SWEL***	
	3,640 ft (23%)	
	55” + 100-yr SWEL	
	13,300 ft (83%)	
Average Depth of Overtopping	***16” + 100-yr SWEL***	
	1.1 ft	
	55” + 100-yr SWEL	
	2.8 ft	
System Responsible (See overview map)	16 (System 3 also a consideration, but does not produce significant inundation.)	

Future Projects
Replacement of the handrail and portions of the sidewalk along both Posey and Webster Street tubes. Restoration of the exterior surface of the portal buildings of Posey tube.

Posey Tube

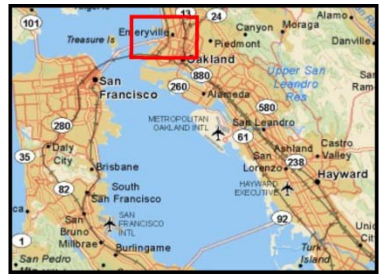


Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL

Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

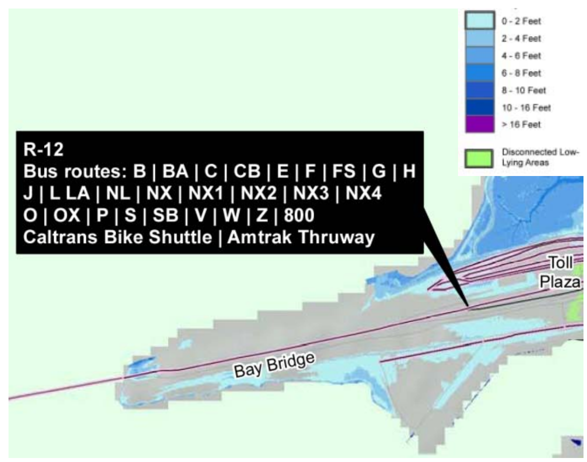
Asset Risk Profile

San Francisco – Oakland Bay Bridge Approach (R-12)

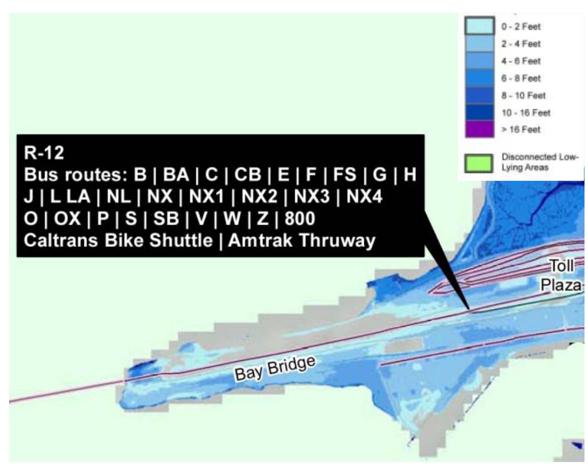


Asset Location / Jurisdiction Oakland / FHWA, Caltrans	
Summary The San Francisco – Oakland Bay Bridge connects Alameda County with the City and County of San Francisco. This profile considers the approach to the bridge. Sensitivity is high (due to relatively high level of use and very high liquefaction potential), while exposure is medium (due to inundation under the 16" + 100-yr SWEL and 55" + MHHW SLR scenarios). When combined with the lack of adequate alternate routes, this results in a high vulnerability rating. All considerations under consequence rate high, with the exception of socioeconomic impact (which is moderate because transit lines only pass through on this asset). The overall consequence is 4.67, making this a high-risk asset.	
Characteristics: • Caltrans Lifeline route • Goods movement • Transit routes [AC Transit: B, BA, C, CB, E, F, FS, G, H, J, L, LA, NL, NX, NX1, NX2, NX3, NX4, O, OX, P, S, SB, V, W, Z, 800; Caltrans Bike Shuttle, Amtrak Thruway] • Commuter route • Regional importance	

Sensitivity: High	
Year Built	1936; widened 1962 New span under construction
Level of Use	
Peak Hour	16,300
AADT	251,000
AADTT	6,476
Seismic Retrofit	New span under construction
Annual O&M	$721,000
Liquefaction Susceptibility	Very High
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW	0 ft
16" + 100-yr SWEL	2 ft
16" + 100-yr SWEL + wind waves	YES
55" + MHHW	2 ft
55" + 100-yr SWEL	5 ft
55" + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16" SLR): Medium BART and ferries provide alternate routes	
Vulnerability Rating (**mid century**)**: High**	



Projected Inundation with 16 inch SLR + 100-yr SWEL



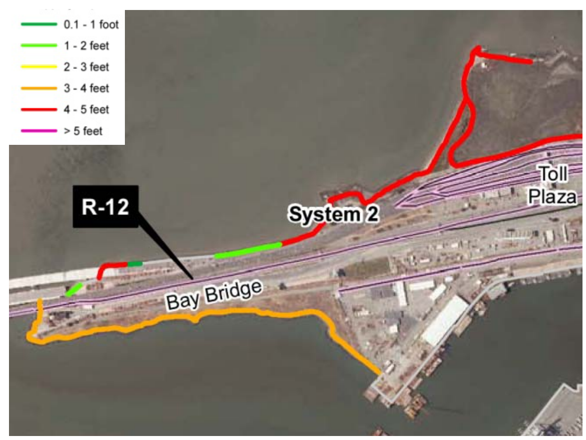
Projected Inundation with 55 inch SLR + 100-yr SWEL

Consequence Rating (out of 5): 4.67	
Capital improvement cost	$5.5 billion (new span) (5)
Time to rebuild	More than 84 months (5)
Public safety	Caltrans Lifeline Highway (5)
Economic impact - goods movement	6,476 AADTT (5)
Economic impact - commuter route	Freeway (and 13,834 daily transit riders) (5)
Socio-economic impact	Pass-through transit (multiple lines) (3)
Risk Rating: High	

Shoreline Asset "Overtopping" Analysis	
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***
	30 ft
	55" + 100-yr SWEL
	30 ft
Length Overtopped (% of System)	***16" + 100-yr SWEL***
	10,510 ft (45%)
	55" + 100-yr SWEL
	16,900 ft (72%)
Average Depth of Overtopping	***16" + 100-yr SWEL***
	1.7 ft
	55" + 100-yr SWEL
	3.9 ft
System Responsible (See overview map)	2

Future Projects
• Rehabilitate Pavement • Install Traffic Operations System

Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

San Mateo Bridge Approach (SR 92) (R-13)

Asset Location / Jurisdiction

Hayward / FHWA, Caltrans

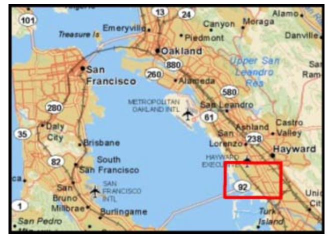
Summary

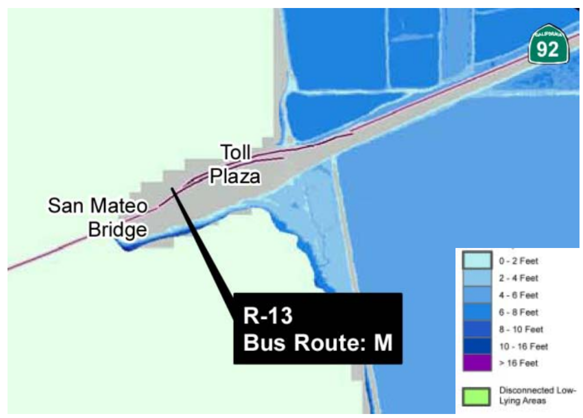
The San Mateo Bridge (SR 92) connects Alameda County with San Mateo County. This profile considers the toll plaza and the approach to the bridge. Sensitivity is medium (due to its relatively moderate level of use and very high liquefaction potential), while exposure is low (due to inundation under only 100-yr SWEL + wind waves for both the 16" and 55" SLR scenarios). When combined with the availability of an adequate alternate route, this results in a medium vulnerability rating. All considerations under consequence rate medium to high, with the exception of socioeconomic impact (which is low because it is used by only a single transit line). The overall consequence is 3.67, making this a medium-risk asset.

Characteristics:

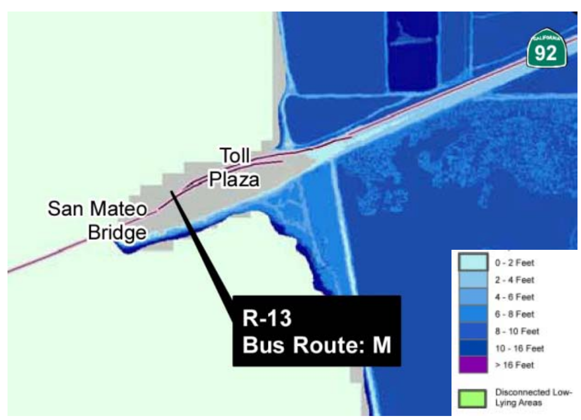
- Goods movement
- Transit routes [AC Transit: M]
- Commuter route
- Regional importance

Sensitivity: Medium	
Year Built	1967; widened 2002
Level of Use	
Peak Hour	7,800
AADT	86,000
AADTT	1,806
Seismic Retrofit	Yes
Annual O&M	$495,000
Liquefaction Susceptibility	Very High
Exposure: Low	
Maximum Inundation Depths	
16” + MHHW	0 ft
16” + 100-yr SWEL	0 ft
16” + 100-yr SWEL + wind waves	YES
55” + MHHW	0 ft
55” + 100-yr SWEL	0 ft
55” + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16” SLR): Medium Dumbarton Bridge provides an alternate route	
Vulnerability Rating (mid century): Medium	





Projected Inundation with 16 inch SLR + 100-yr SWEL

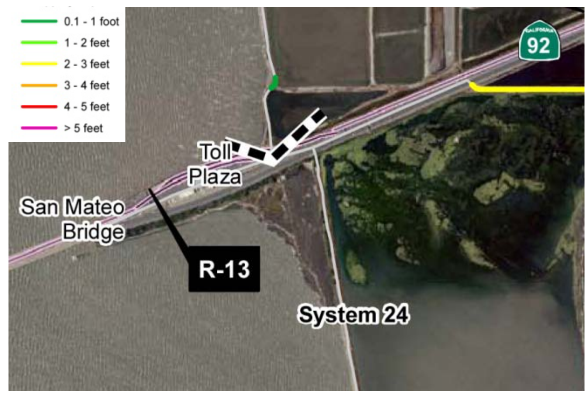


Projected Inundation with 55 inch SLR + 100-yr SWEL

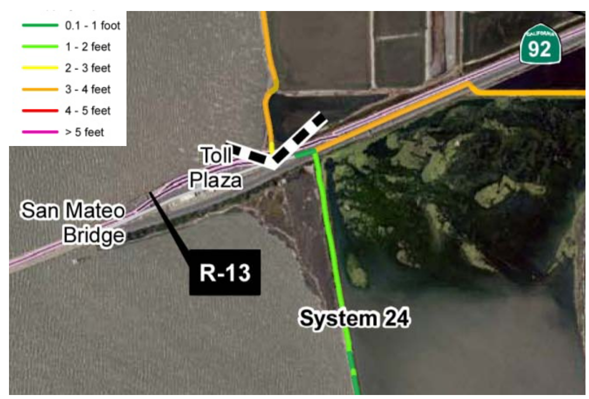
Consequence Rating (out of 5): 3.67	
Capital improvement cost	$560 million (5)
Time to rebuild	84 months (5)
Public safety	Freeway (3)
Economic impact - goods movement	1,806 AADTT (3)
Economic impact - commuter route	Freeway (and 491 daily transit riders) (5)
Socio-economic impact	Pass-through transit (1)
Risk Rating: Medium	

Shoreline Asset "Overtopping" Analysis	
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***
	710 ft
	55" + 100-yr SWEL
	700 ft
Length Overtopped (% of System)	***16" + 100-yr SWEL***
	34,790 ft (26%)
	55" + 100-yr SWEL
	125,270 ft (93%)
Average Depth of Overtopping	***16" + 100-yr SWEL***
	1.6 ft
	55" + 100-yr SWEL
	3.2 ft
System Responsible (See overview map)	23, 24

Future Projects
• Replacement of petroleum underground storage tanks at the toll plaza maintenance facility



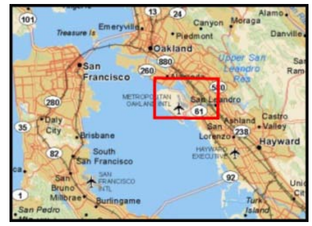
Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

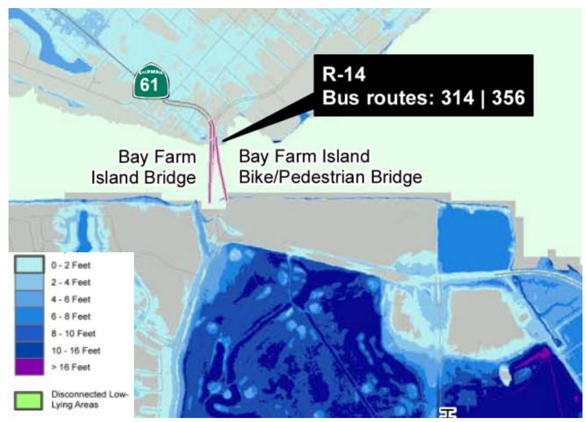
Asset Risk Profile

Bay Farm Island Bridge (R-14)

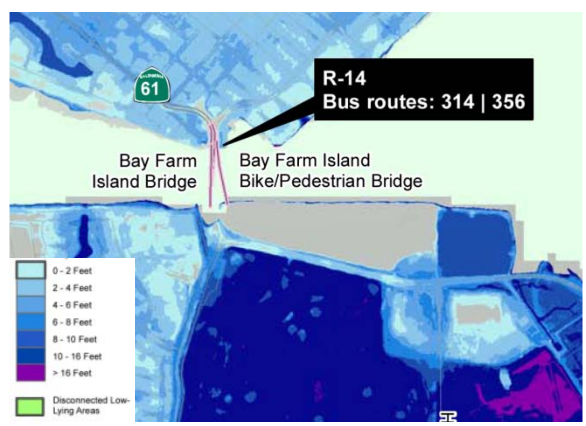


Asset Location / Jurisdiction
Alameda / Caltrans
Summary Bay Farm Island Bridge connects Alameda Island and Bay Farm Island in the City of Alameda, and is part of State Route 61. As this is a unique asset, a comparative rating for sensitivity does not apply. The bridge rates medium for exposure (due to inundation under the 55" + MHHW SLR scenario). No adequate alternative exists for the bridge, resulting in a high vulnerability rating overall. Consequence rates high for capital improvement cost and time to rebuild, while all other considerations have moderate ratings. The overall consequence rating is 3.33, making the bridge a medium-risk asset.
Characteristics: • Drawbridge • Alameda Evacuation Route • Goods movement • Bike route • Transit routes [AC Transit: OX, 21, 314, 356]

Sensitivity	
Year Built	1953
Level of Use	
Peak Hour	3,650
AADT	38,500
AADTT	966
Seismic Retrofit	No
Annual O&M	$45,000
Liquefaction Susceptibility	Very High
Exposure: Medium	
Maximum Inundation Depths	
16” + MHHW	0 ft
16” + 100-yr SWEL	0 ft
16” + 100-yr SWEL + wind waves	YES
55” + MHHW	1 ft
55” + 100-yr SWEL	4 ft
55” + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16” SLR): High No adequate alternative	
Vulnerability Rating (mid century): High	



Projected Inundation with 16 inch SLR + 100-yr SWEL

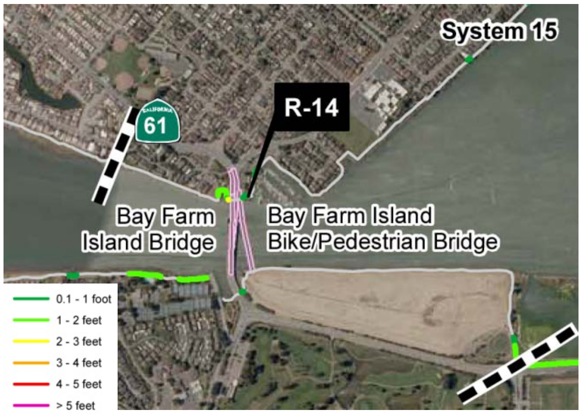


Projected Inundation with 55 inch SLR + 100-yr SWEL

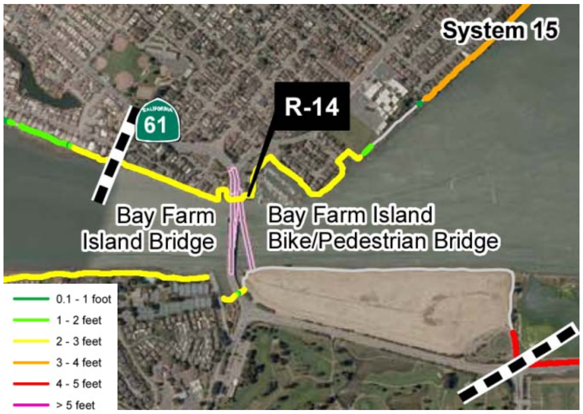
Consequence Rating (out of 5): 3.33	
Capital improvement cost	$26.7 million (3)
Time to rebuild	84 months (5)
Public safety	Alameda Evacuation Route (3)
Economic impact - goods movement	966 AADTT (3)
Economic impact - commuter route	2,760 daily transit riders (3)
Socio-economic impact	Pass-through transit (multiple lines) (3)
Risk Rating: Medium	

Shoreline Asset "Overtopping" Analysis		
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***	30 ft
	55" + 100-yr SWEL	0 ft
Length Overtopped (% of System)	***16" + 100-yr SWEL***	6,130 ft (13%)
	55" + 100-yr SWEL	33,140 ft (71%)
Average Depth of Overtopping	***16" + 100-yr SWEL***	1.4 ft
	55" + 100-yr SWEL	2.5 ft
System Responsible (See overview map)	7, 15	

Future Projects
None



Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

BART Transbay Tube (T-01)

Asset Location / Jurisdiction
Oakland / BART
Summary The Transbay Tube is a core component of the BART system, connecting Alameda and other East Bay counties with the City and County of San Francisco and San Mateo County on the Peninsula. Due to lack of data, this asset was not rated with respect to sensitivity. Exposure is medium due to inundation under the 55" + 100-yr SWEL SLR scenario. Because BART trains cannot be rerouted, the Transbay Tube has inadequate adaptive capacity, resulting in an overall vulnerability rating of medium-high. High capital improvement costs, rebuilding time, public safety consequence and commuter use result in a consequence rating of 4.00, making this a high-risk asset.
Characteristics: • Subgrade • Transit routes [4 BART lines] • Commuter route • Regional importance

Sensitivity	
Information unavailable in project timeframe.	
Liquefaction Susceptibility	Very High
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW 16" + 100-yr SWEL 16" + 100-yr SWEL + wind waves	0 ft 0 ft YES
55" + MHHW 55" + 100-yr SWEL 55" + 100-yr SWEL + wind waves	0 ft 18 ft* YES
Inadequate Adaptive Capacity (16" SLR): High No possible rerouting	
Vulnerability Rating (**mid century**)**: Medium-High**	

*High inundation depth is due to below-grade alignment

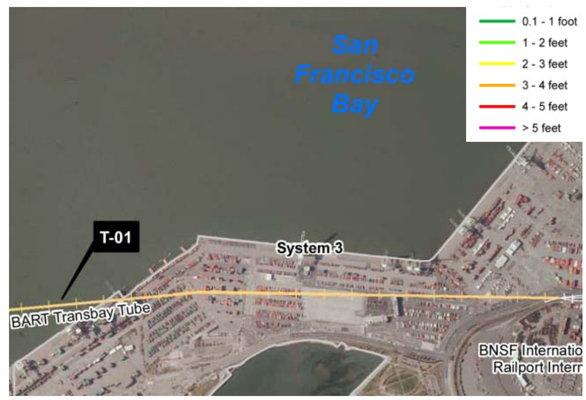
Projected Inundation with 16 inch SLR + 100-yr SWEL

Projected Inundation with 55 inch SLR + 100-yr SWEL

Consequence Rating (out of 5): 4.00	
Capital improvement cost	One of the most expensive components of the BART system (5)
Time to rebuild	Construction originally took 9 years (5)
Public safety	Regional significance, alternative to Bay Bridge (5)
Economic impact - goods movement	Not applicable (1)
Economic impact - commuter route	175,546 daily transit riders (5)
Socio-economic impact	Pass-though transit (multiple lines) (3)
Risk Rating: High	

Shoreline Asset "Overtopping" Analysis	
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***
	2,970 ft
	55" + 100-yr SWEL
	2,660 ft
Length Overtopped (% of System)	***16" + 100-yr SWEL***
	5,800 ft (12%)
	55" + 100-yr SWEL
	20,780 ft (41%)
Average Depth of Overtopping	***16" + 100-yr SWEL***
	1.4 ft
	55" + 100-yr SWEL
	2.6 ft
System Responsible (See overview map)	3

Future Projects
None

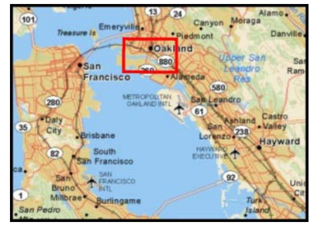


Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL

Projected Overtopping Depth at 55 inch SLR + 100- yr SWEL

Asset Risk Profile

Elevated BART Line between Transbay Tube and Oakland Wye (T-02)



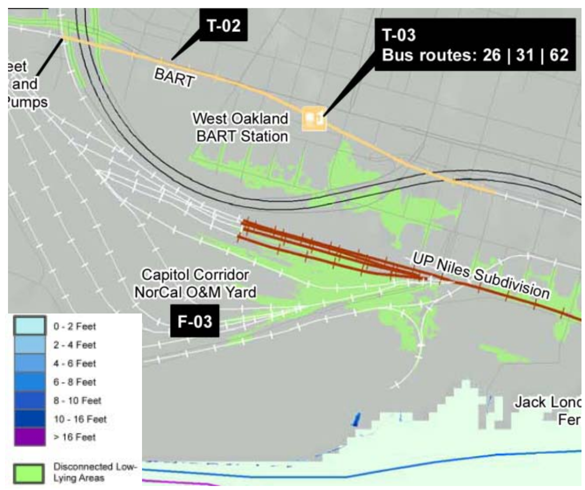
Asset Location / Jurisdiction
Oakland / BART

Summary
The BART line between the Transbay Tube and Oakland Wye is an elevated guideway traveled by four of the five lines of the BART system, and includes West Oakland BART Station (profiled separately). Due to lack of data, this asset was not rated with respect to sensitivity. Exposure is medium due to inundation under the 55" + 100-yr SLR scenario. No possible rerouting exists for the asset, resulting in a medium-high vulnerability rating. As an alternate to the Bay Bridge, consequence is high for public safety and commuter use, and moderate for other considerations except goods movement, which does not apply. The overall consequence rating is 3.33, making this a medium-risk asset.

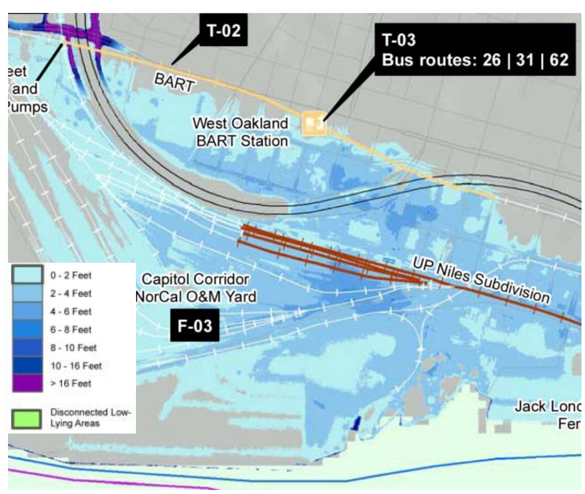
Characteristics:
- Elevated
- Transit routes [4 BART lines]
- Commuter route
- Regional importance

Sensitivity	
Information unavailable in project timeframe.	
Liquefaction Susceptibility	Medium
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW	0 ft
16" + 100-yr SWEL	0 ft
16" + 100-yr SWEL + wind waves	YES
55" + MHHW	0 ft
55" + 100-yr SWEL	24 ft*
55" + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16" SLR): High No possible rerouting	
Vulnerability Rating (mid century): Medium-High	

*High inundation depth is due to below-grade road segment below the BART Trackway



Projected Inundation with 16 inch SLR + 100-yr SWEL

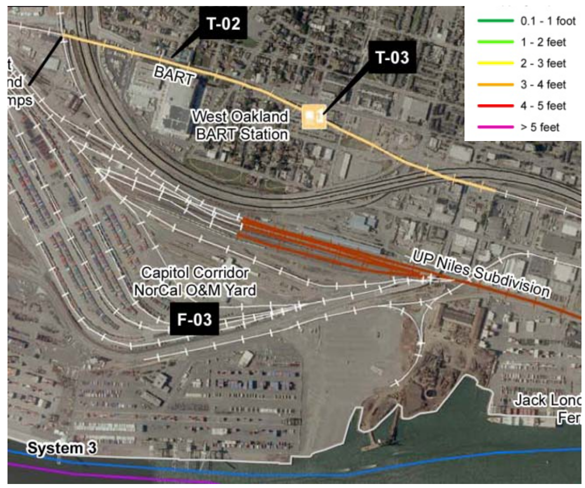


Projected Inundation with 55 inch SLR + 100-yr SWEL

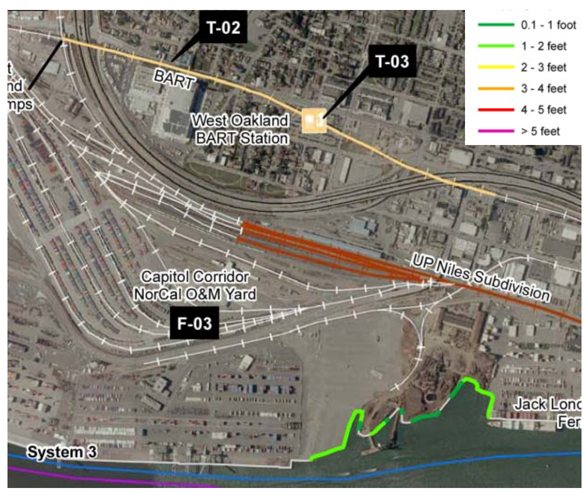
Consequence Rating (out of 5): 3.33	
Capital improvement cost	Likely $20-50 million excluding station (3)
Time to rebuild	Likely within 5 years (3)
Public safety	Regional significance, alternative to Bay Bridge (5)
Economic impact - goods movement	Not applicable (1)
Economic impact - commuter route	169,011 daily transit riders (5)
Socio-economic impact	Community of Concern + Transit-Dependent area; pass-though transit (multiple lines) (3)
Risk Rating: Medium	

Shoreline Asset "Overtopping" Analysis		
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***	3,130 ft
	55" + 100-yr SWEL	3,130 ft
Length Overtopped (% of System)	***16" + 100-yr SWEL***	5,800 ft (12%)
	55" + 100-yr SWEL	20,780 ft (41%)
Average Depth of Overtopping	***16" + 100-yr SWEL***	1.4 ft
	55" + 100-yr SWEL	2.6 ft
System Responsible (See overview map)	3	

Future Projects
None



Projected Overtopping Depth at 16 inch SLR + 100yr SWEL



Projected Overtopping Depth at 55 inch SLR + 100yr SWEL

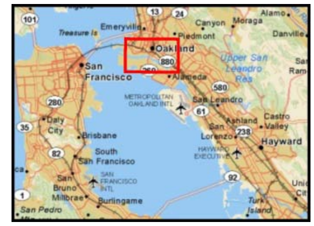
Asset Risk Profile

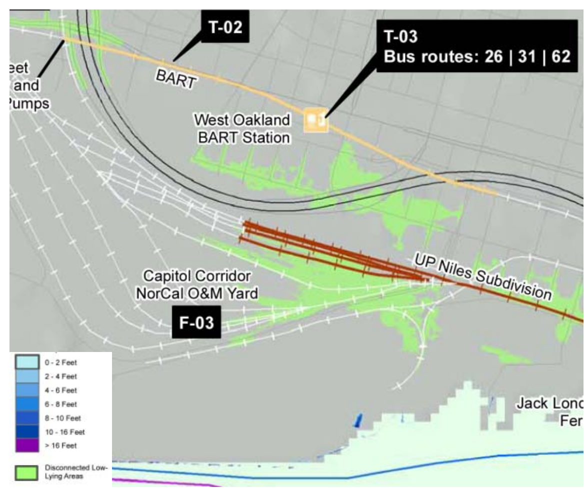
West Oakland BART Station (T-03)

Asset Location / Jurisdiction
Oakland / BART
Summary West Oakland BART Station is a transit facility serving West Oakland neighborhoods and includes bus transfer and parking facilities. Due to lack of data, this asset was not rated with respect to sensitivity. Exposure is rated low, due to inundation under only 100-year SWEL + wind/waves for both the 16" and 55" SLR scenarios. No adequate alternative station exists for West Oakland BART Station, resulting in a medium vulnerability rating. Consequence is rated high for capital improvement costs, commuter use, and socioeconomic impact; moderate for time to rebuild; and low for public safety and goods movement, which does not apply. The overall consequence rating for this asset is 3.33, making this a medium-risk asset.
Characteristics: • Elevated • Commuter route • Transit routes [4 BART lines; AC Transit: 26, 31, 62]

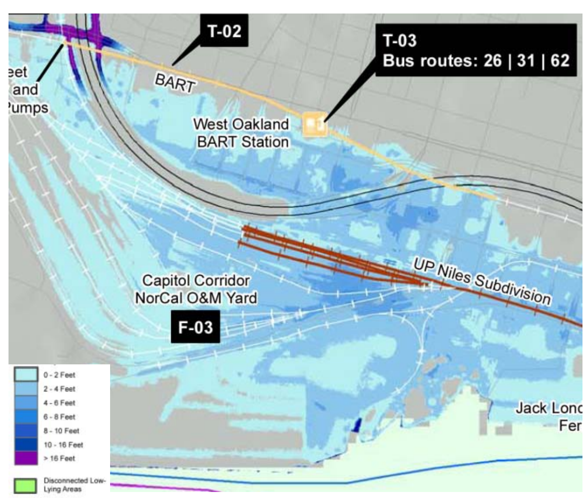
Sensitivity	
Data unavailable in project timeframe.	
Annual O&M	$3.43 million
Liquefaction Susceptibility	Medium
Exposure: Low	
Maximum Inundation Depths	
16” + MHHW	0 ft
16” + 100-yr SWEL	0 ft
16” + 100-yr SWEL + wind waves	YES
55” + MHHW	0 ft
55” + 100-yr SWEL	0 ft*
55” + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16” SLR): High No adequate alternative station	
Vulnerability Rating (mid century): Medium	

* The BART station is elevated, hence no inundation at the 55” + 100-yr SWEL scenario, although access to the station will be impacted





Projected Inundation with 16 inch SLR + 100-yr SWEL

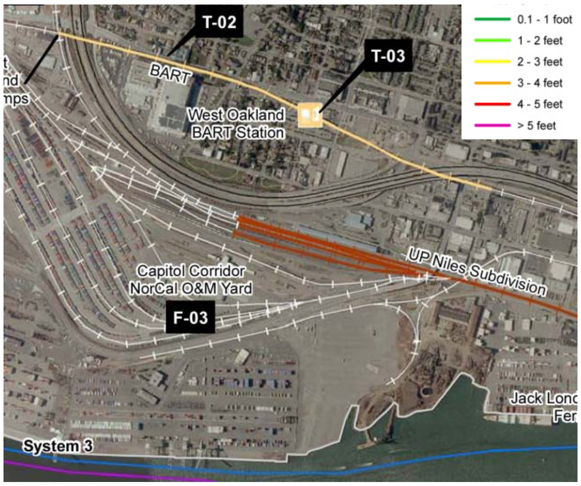


Projected Inundation with 55 inch SLR + 100-yr SWEL

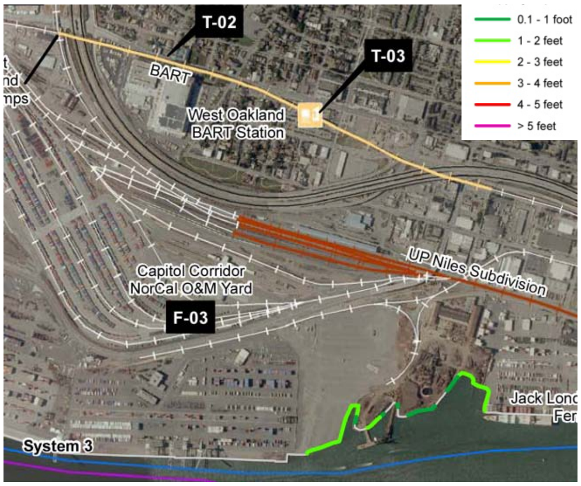
Consequence Rating (out of 5): 3.33	
Capital improvement cost	West / Dublin Pleasanton Station cost $106 million (5)
Time to rebuild	West Dublin / Pleasanton Station construction planned at 3 years (3)
Public safety	Minor consequence (1)
Economic impact - goods movement	Not applicable (1)
Economic impact - commuter route	10,741 daily BART riders (5)
Socio-economic impact	Community of Concern + Transit-Dependent area; local transit access (multiple lines) (5)
Risk Rating: Medium	

Shoreline Asset "Overtopping" Analysis		
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***	5,330 ft
	55" + 100-yr SWEL	3,560 ft
Length Overtopped (% of System)	***16" + 100-yr SWEL***	5,800 ft (12%)
	55" + 100-yr SWEL	20,780 ft (41%)
Average Depth of Overtopping	***16" + 100-yr SWEL***	1.4 ft
	55" + 100-yr SWEL	2.6 ft
System Responsible (See overview map)	Inundation adjacent to BART station appears to trace back to very short segment of overtopped shoreline (~450 ft)	

Future Projects
None



Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL

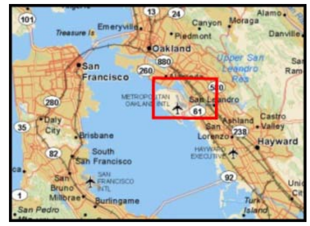


Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

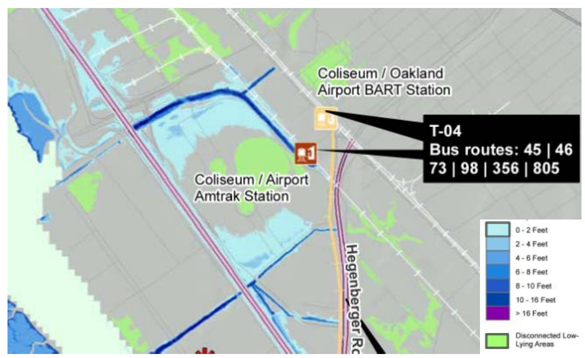
Coliseum / Oakland Airport BART Station (T-04)

Asset Location / Jurisdiction
Oakland / BART
Summary The Coliseum / Oakland Airport BART Station is a transit facility serving East Oakland neighborhoods and includes bus transfer and parking facilities. Pedestrian connections are available to Oakland Coliseum Amtrak Station, and frequent and direct bus service is provided from the BART station to Oakland International Airport. The future Oakland Airport BART Connector, currently under construction, will provide an automated guideway transit connection between the station and the airport. Due to lack of data, this asset was not rated with respect to sensitivity. Exposure is rated low, due to inundation under only 100-year SWEL + wind waves for both the 16" and 55" SLR scenarios. No adequate alternative station exists for the Coliseum / Oakland Airport BART Station, resulting in a medium vulnerability rating. Consequence is rated high for capital improvement costs, commuter use, and socioeconomic impact; moderate for time to rebuild; and low for public safety and goods movement, which does not apply. The overall consequence rating is 3.33, making this a medium-risk asset.
Characteristics: • Elevated • Commuter route • Transit routes [3 BART Lines; AC Transit: 45, 46, 73, 98, 356, 805]



Sensitivity	
Data unavailable in project timeframe.	
Liquefaction Susceptibility	Medium
Exposure: Low	
Maximum Inundation Depths	
16" + MHHW	0 ft
16" + 100-yr SWEL	0 ft
16" + 100-yr SWEL + wind waves	YES
55" + MHHW	0 ft
55" + 100-yr SWEL	0 ft*
55" + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16" SLR): High No adequate alternative station	
Vulnerability Rating (mid century): Medium	

*The asset is inundated to 0.3 ft at 55" + 100-yr SWEL SLR scenario, which was rounded down to 0 ft due to resolution limitations of the mapping



Projected Inundation with 16 inch SLR + 100-yr SWEL

Projected Inundation with 55 inch SLR + 100-yr SWEL

Consequence Rating (out of 5): 3.33	
Capital improvement cost	West / Dublin Pleasanton Station cost $106 million (5)
Time to rebuild	West Dublin / Pleasanton Station construction planned at 3 years (3)
Public safety	Minor consequence (1)
Economic impact - goods movement	Not applicable (1)
Economic impact - commuter route	12,132 daily BART riders (5)
Socio-economic impact	Community of Concern + Transit-Dependent area; local transit access (multiple lines) (5)
Risk Rating: Medium	

Shoreline Asset “Overtopping” Analysis		
Proximity to Overtopping (distance)	***16” + 100-yr SWEL***	1,270 ft
	55” + 100-yr SWEL	710 ft
Length Overtopped (% of System)	***16” + 100-yr SWEL***	3,640 ft (18%)
	55” + 100-yr SWEL	18,790 ft (95%)
Average Depth of Overtopping	***16” + 100-yr SWEL***	0.9 ft
	55” + 100-yr SWEL	3.1 ft
System Responsible (See overview map)	10	

Future Projects
Oakland Airport BART Connector under construction

Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL

Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

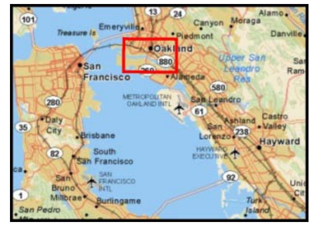
Oakland Jack London Square Amtrak Station (T-05)

Asset Location / Jurisdiction
Oakland / Amtrak

Summary
The Oakland Jack London Square Amtrak Station is an at-grade, multi-modal facility on the Capitol Corridor. Due to lack of data, this asset was not rated with respect to sensitivity. Exposure is rated medium, due to inundation under the 55" + 100-yr SWEL SLR scenario. Emeryville Amtrak Station, located about 4 miles away, provides an alternative route, resulting in a medium vulnerability rating. Consequence is rated moderate for time to rebuild and commuter use, and low for all other considerations. The overall consequence rating is 1.67, making this a low-risk asset.

Characteristics:
- At grade
- Transit routes [AC Transit: 58L, 72, 72M]

Sensitivity	
Data unavailable in project timeframe.	
Liquefaction Susceptibility	Very High
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW	0 ft
16" + 100-yr SWEL	0 ft
16" + 100-yr SWEL + wind waves	YES
55" + MHHW	0 ft
55" + 100-yr SWEL	1 ft
55" + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16" SLR): Medium Emeryville Station provides an alternative but is located about 4 miles away	
Vulnerability Rating (**mid century**)**: Medium**	



Projected Inundation with 16 inch SLR + 100-yr SWEL

Projected Inundation with 55 inch SLR + 100-yr SWEL

Consequence Rating (out of 5): 1.67	
Capital improvement cost	$15 million (estimated cost) (1)
Time to rebuild	Opened 5 years after Loma Prieta Earthquake damaged predecessor
Public safety	Minor consequence (1)
Economic impact - goods movement	Not applicable (1)
Economic impact - commuter route	950 daily Amtrak riders (3)
Socio-economic impact	Community of Concern; “Premium“ transit (1)
Risk Rating: Low	

Shoreline Asset “Overtopping” Analysis		
Proximity to Overtopping (distance)	***16” + 100-yr SWEL***	790 ft
	55” + 100-yr SWEL	790 ft
Length Overtopped (% of System)	***16” + 100-yr SWEL***	5,800 ft (12%)
	55” + 100-yr SWEL	20,780 ft (41%)
Average Depth of Overtopping	***16” + 100-yr SWEL***	1.4 ft
	55” + 100-yr SWEL	2.6 ft
System Responsible (See overview map)	3	

Future Projects
None

Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL

Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

UP Martinez Subdivision (T-06)

Asset Location / Jurisdiction

Oakland / Union Pacific Railroad

Summary

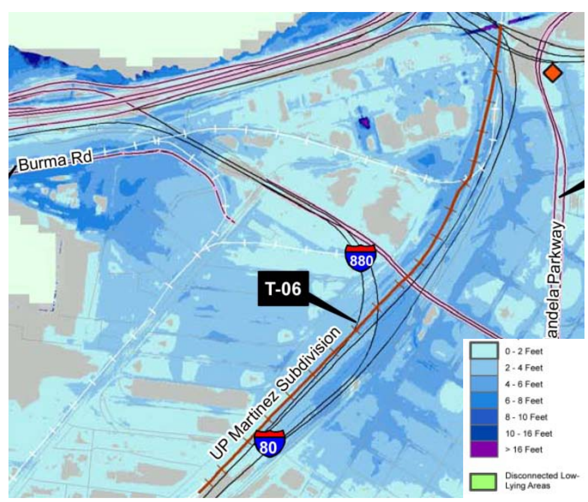
The Martinez Subdivision is owned by Union Pacific Railroad and serves passenger and freight operations. This profile considers the segment between the 10th Street and 34th Street Crossovers in Oakland. Due to lack of data, this asset was not rated with respect to sensitivity. Exposure is rated medium, due to inundation under the 55" + MHHW SLR scenario. No adequate alternative exists for this asset, resulting in a medium-high vulnerability rating. Consequence is rated high for goods movement; moderate for capital improvement costs and commuter use; and low for all other considerations. The overall consequence rating is 2.33, making this a medium-risk asset.

Characteristics:

- At grade
- Passenger and freight operations

Sensitivity	
Data unavailable in project timeframe.	
Liquefaction Susceptibility	Very High
Exposure: Medium	
Maximum Inundation Depths	
16” + MHHW	0 ft
16” + 100-yr SWEL	0 ft
16” + 100-yr SWEL + wind waves	YES
55” + MHHW	3 ft
55” + 100-yr SWEL	5 ft
55” + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16” SLR): High	
No adequate alternative	
Vulnerability Rating (mid century): Medium-High	

Projected Inundation with 16 inch SLR + 100-yr SWEL



Projected Inundation with 55 inch SLR + 100-yr SWEL

Consequence Rating (out of 5): 2.33	
Capital improvement cost	At-grade railroad, likely at least $20 million per mile (5)
Time to rebuild	At-grade with no bridges, likely within 2 years (1)
Public safety	Minor consequence (1)
Economic impact - goods movement	Connects Port of Oakland to regional/national rail network (5)
Economic impact - commuter route	4,330 daily riders for entire Capitol Corridor (3)
Socio-economic impact	Transit-Dependent area; pass-through “Premium” transit (1)
Risk Rating: Medium	

Shoreline Asset “Overtopping” Analysis	
Proximity to Overtopping (distance)	***16” + 100-yr SWEL***
	1,160 ft
	55” + 100-yr SWEL
	1,160 ft
Length Overtopped (% of System)	***16” + 100-yr SWEL***
	10,510 ft (45%)
	55” + 100-yr SWEL
	16,900 ft (72%)
Average Depth of Overtopping	***16” + 100-yr SWEL***
	1.7 ft
	55” + 100-yr SWEL
	3.9 ft
System Responsible (See overview map)	2 Asset is landward of System 3, but shoreline overtopping does not contribute to inundation of asset.

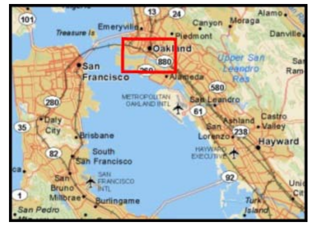
Future Projects
None

Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL

Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

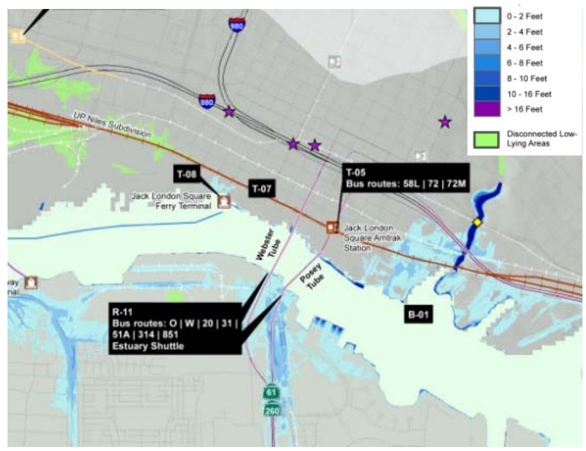
Asset Risk Profile

UP Niles Subdivision (T-07)

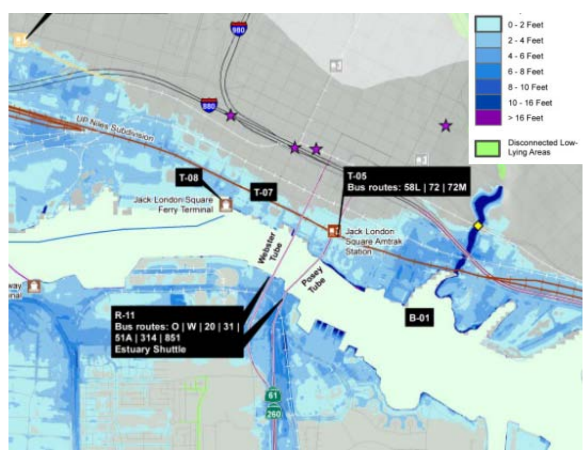


Asset Location / Jurisdiction Oakland / Union Pacific Railroad	
Summary The Niles Subdivision is owned by Union Pacific Railroad and serves passenger and freight operations. This profile considers the segment between the Magnolia Crossover and East Oakland Yard in Oakland. Due to lack of data, this asset was not rated with respect to sensitivity. Exposure is rated medium, due to inundation under both the 16" + 100-yr SWEL and 55" + MHHW SLR scenarios. No adequate alternative exists for this asset, resulting in a medium-high vulnerability rating. Consequence is rated high for capital improvement costs and goods movement, moderate for time to rebuild and commuter use, and low for public safety and socioeconomic impact. The overall consequence rating is 3.00, making this a medium-risk asset.	
Characteristics: • At grade • Passenger and freight operations	

Sensitivity	
Data unavailable in project timeframe.	
Liquefaction Susceptibility	Very High
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW	0 ft
16" + 100-yr SWEL	1 ft
16" + 100-yr SWEL + wind waves	YES
55" + MHHW	2 ft
55" + 100-yr SWEL	4 ft
55" + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16" SLR): High No adequate alternative	
Vulnerability Rating (**mid century**): **Medium-High**	



Projected Inundation with 16 inch SLR + 100-yr SWEL

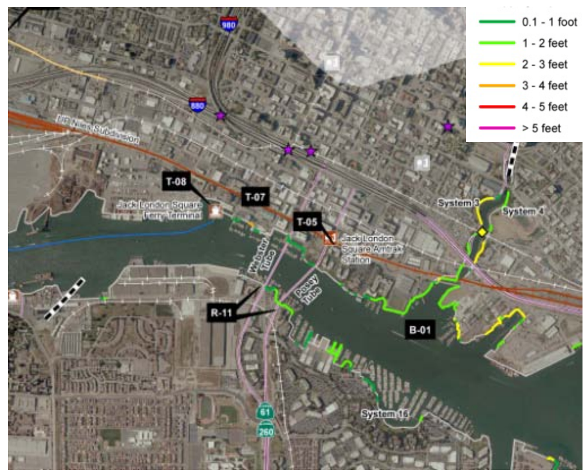


Projected Inundation with 55 inch SLR + 100-yr SWEL

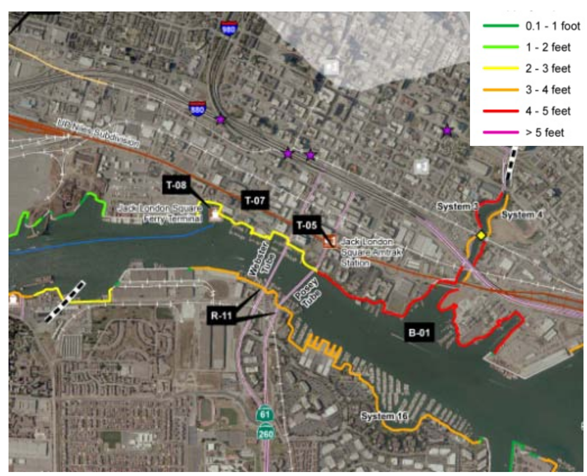
Consequence Rating (out of 5): 3.00	
Capital improvement cost	At-grade railroad plus bridge over Lake Merritt inlet to cost at least $50 million (5)
Time to rebuild	At-grade, plus bridge over Lake Merritt inlet, likely within 5 years (3)
Public safety	Minor consequence (1)
Economic impact - goods movement	Connects Port of Oakland to regional/national rail network (5)
Economic impact - commuter route	4,330 daily riders for entire Capitol Corridor (3)
Socio-economic impact	Community of Concern; pass-through “Premium” transit (1)
Risk Rating: Medium	

Shoreline Asset “Overtopping” Analysis	
Proximity to Overtopping (distance)	***16” + 100-yr SWEL***
	< 10 ft
	55” + 100-yr SWEL
	< 10 ft
Length Overtopped (% of System)	***16” + 100-yr SWEL***
	10,470 ft (17%)
	55” + 100-yr SWEL
	29,870 ft (48%)
Average Depth of Overtopping	***16” + 100-yr SWEL***
	1.5 ft
	55” + 100-yr SWEL
	3.0 ft
System Responsible (See overview map)	3, 4

Future Projects
None

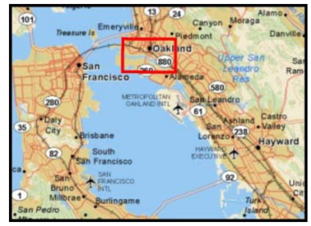


Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Jack London Square Ferry Terminal (T-08)



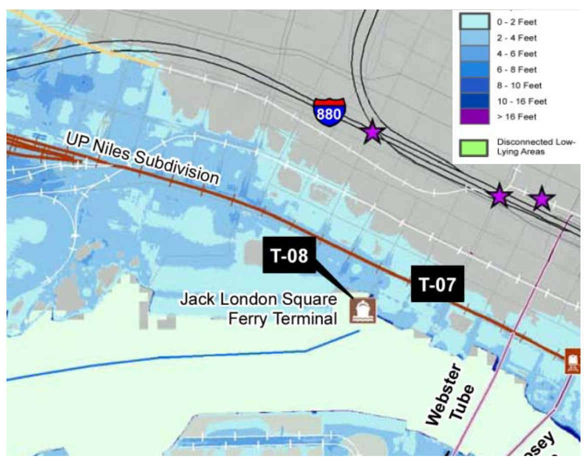
Asset Location / Jurisdiction
Oakland / WETA

Summary
The Jack London Square Ferry Terminal facilitates ferry service between Oakland and San Francisco. Sensitivity is high (due to immediate maintenance needs), while exposure is medium (due to inundation under the 55" + MHHW SLR scenario). No adequate alternative exists for this asset, resulting in a high vulnerability rating. Consequence is rated moderate for commuter use and public safety, given the role of ferries in disaster response and recovery, and low for all other considerations. The overall consequence rating is 1.67, making this a low-risk asset.

Characteristics:
- Transit routes: [1 ferry route]

Sensitivity: High	
Built	ca. 1991
Level of Use	13 ferries/day 239,000 trips/year
Seismic Retrofit	No
Annual O&M	$12,000-$15,000
Liquefaction Susceptibility	Very High
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW 16" + 100-yr SWEL 16" + 100-yr SWEL + wind waves	0 ft 0 ft YES
55" + MHHW 55" + 100-yr SWEL 55" + 100-yr SWEL + wind waves	1 ft 3 ft YES
Inadequate Adaptive Capacity (16" SLR): High No adequate alternative	
Vulnerability Rating (**mid century**)**: High**	

Projected Inundation with 16 inch SLR + 100-yr SWEL

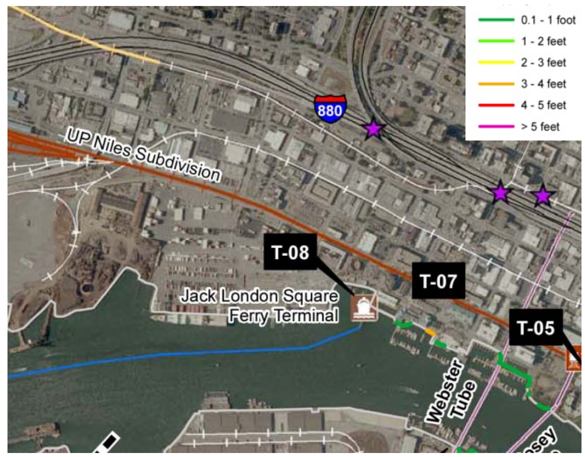


Projected Inundation with 55 inch SLR + 100-yr SWEL

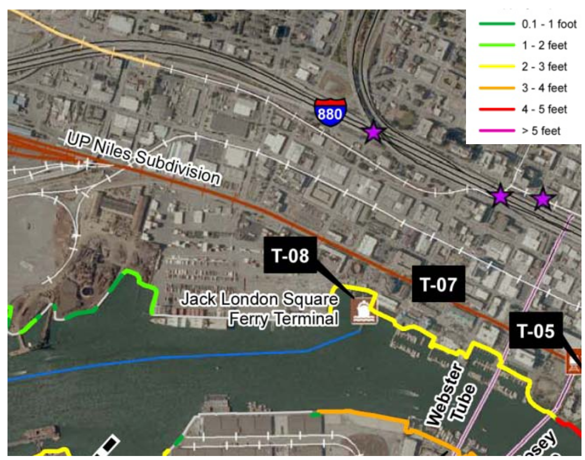
Consequence Rating (out of 5): 1.67	
Capital improvement cost	$15-20 million for total replacement (1)
Time to rebuild	18-24 months from start of construction (1)
Public safety	Critical to immediate disaster response and recovery (3)
Economic impact - goods movement	Not applicable (1)
Economic impact - commuter route	605 daily ferry riders (3)
Socio-economic impact	Community of Concern; local “Premium” transit (1)
Risk Rating: Low	

Shoreline Asset “Overtopping” Analysis	
Proximity to Overtopping (distance)	***16” + 100-yr SWEL***
	330 ft
	55” + 100-yr SWEL
	< 10 ft
Length Overtopped (% of System)	***16” + 100-yr SWEL***
	5,800 ft (12%)
	55” + 100-yr SWEL
	20,780 ft (41%)
Average Depth of Overtopping	***16” + 100-yr SWEL***
	1.4 ft
	55” + 100-yr SWEL
	2.6 ft
System Responsible (See overview map)	3

Future Projects
None



Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



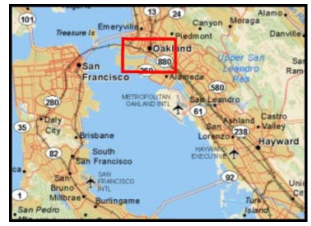
Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Alameda Gateway Ferry Terminal (T-09)

Asset Location / Jurisdiction
Oakland / WETA

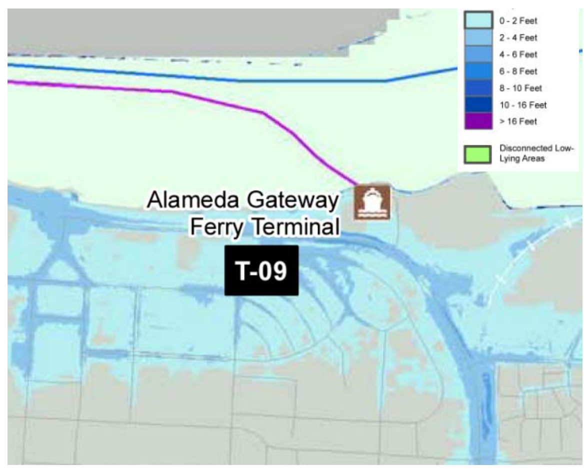
Summary
The Alameda Gateway Ferry Terminal facilitates ferry service between Alameda and the City and County of San Francisco, and includes parking, bicycle and ADA access. Sensitivity is medium (due to 'fair' condition), as is exposure (due to inundation under the 55" + 100-yr SWEL SLR scenario). No adequate alternative exists for this asset, resulting in a high vulnerability rating. Consequence is moderate for commuter use and public safety, given the role of ferries in disaster response and recovery, and low for all other considerations. The overall consequence rating is 1.67, making this a low-risk asset.

Characteristics:
- Transit routes: [1 ferry route]

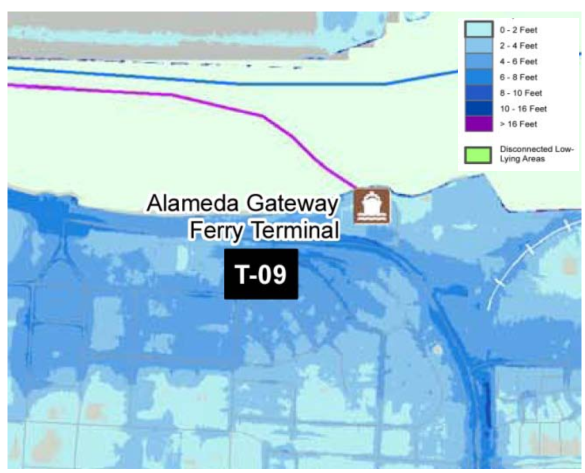


Sensitivity: Medium	
Built	ca. 1991
Level of Use	13 ferries/day 239,000 trips/year
Seismic Retrofit	No
Annual O&M	$5,000-$10,000
Liquefaction Susceptibility	Very High
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW 16" + 100-yr SWEL 16" + 100-yr SWEL + wind waves	0 ft 0 ft* YES
55" + MHHW 55" + 100-yr SWEL 55" + 100-yr SWEL + wind waves	0 ft 2 ft YES
Inadequate Adaptive Capacity (16" SLR): High No adequate alternative	
Vulnerability Rating (mid century): High	

*The asset is inundated to 0.05 ft at the 16" + 100-yr SWEL scenario, which was rounded down due to resolution limitations of the mapping



Projected Inundation with 16 inch SLR + 100-yr SWEL

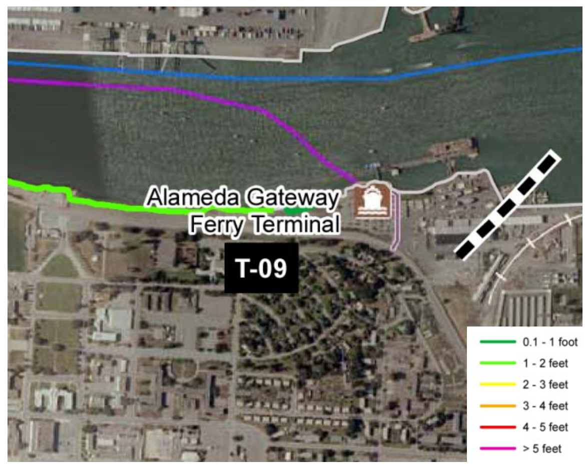


Projected Inundation with 55 inch SLR + 100-yr SWEL

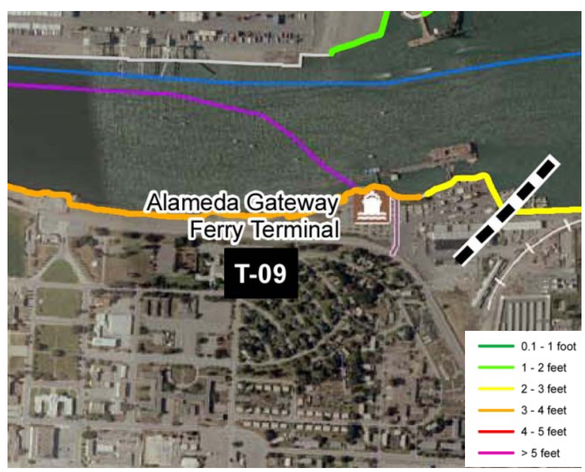
Consequence Rating (out of 5): 1.67	
Capital improvement cost	$15-20 million for total replacement (1)
Time to rebuild	18-24 months from start of construction (1)
Public safety	Critical to immediate disaster response and recovery (3)
Economic impact - goods movement	Not applicable (1)
Economic impact - commuter route	655 daily ferry riders (3)
Socio-economic impact	Community of Concern; local "Premium" transit (1)
Risk Rating: Low	

Shoreline Asset "Overtopping" Analysis	
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***
	560 ft
	55" + 100-yr SWEL
	50 ft
Length Overtopped (% of System)	***16" + 100-yr SWEL***
	14,970 ft (49%)
	55" + 100-yr SWEL
	25,840 ft (85%)
Average Depth of Overtopping	***16" + 100-yr SWEL***
	1.1 ft
	55" + 100-yr SWEL
	3.6 ft
System Responsible (See overview map)	12

Future Projects
None



Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

AC Transit Maintenance Facility (1100 Seminary Avenue) (F-01)

Asset Location / Jurisdiction
Oakland / AC Transit

Summary
AC Transit operates a bus maintenance and storage facility at 1100 Seminary Avenue in Oakland. Due to lack of data, this asset was not rated with respect to sensitivity. Exposure is rated medium, due to inundation under the 55" + 100-yr SWEL SLR scenario. AC Transit operates other maintenance facilities, but they are likely insufficient to fully compensate for loss of this facility, resulting in a medium vulnerability rating for this asset. Consequence is rated high for capital improvement costs, time to rebuild, and commuter use; moderate for time to rebuild and socioeconomic impact; and low for public safety and goods movement, which does not apply. The overall consequence rating is 3.00, making this a medium-risk asset.

Characteristics:

- At grade
- Maintenance facility

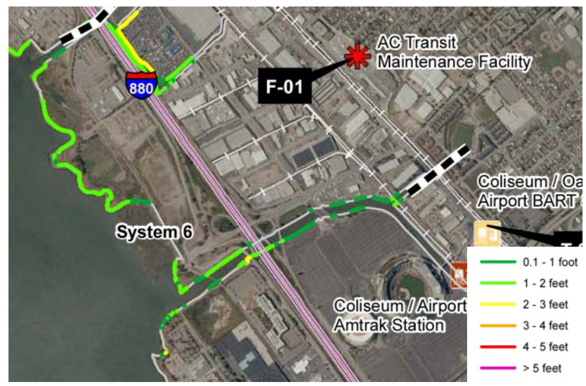
Sensitivity	
Data unavailable in project timeframe.	
Liquefaction Susceptibility	Medium
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW	0 ft
16" + 100-yr SWEL	0 ft
16" + 100-yr SWEL + wind waves	YES
55" + MHHW	0 ft
55" + 100-yr SWEL	2 ft
55" + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16" SLR): Medium AC Transit maintains other maintenance facilities, but they are likely insufficient to fully compensate for loss of this facility	
Vulnerability Rating (mid century): Medium	

Projected Inundation with 16 inch SLR + 100-yr SWEL

Projected Inundation with 55 inch SLR + 100-yr SWEL

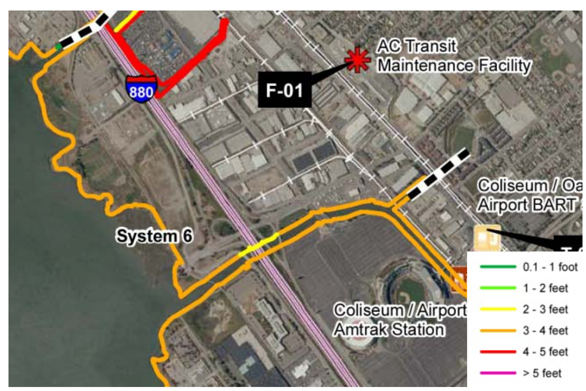
Consequence Rating (out of 5): 3.00	
Capital improvement cost	$87 million (estimate from new bus maintenance facility in Nevada) (5)
Time to rebuild	Likely within 5 years (3)
Public safety	Minor consequence (1)
Economic impact - goods movement	Not applicable (1)
Economic impact - commuter route	Critical to providing AC Transit service (5)
Socio-economic impact	Community of Concern + Transit-Dependent area; supporting local transit (multiple lines) (5)
Risk Rating: Medium	

Shoreline Asset "Overtopping" Analysis	
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***
	1,540 ft
	55" + 100-yr SWEL
	1,360 ft
Length Overtopped (% of System)	***16" + 100-yr SWEL***
	7,840 ft (47%)
	55" + 100-yr SWEL
	16,170 ft (98%)
Average Depth of Overtopping	***16" + 100-yr SWEL***
	1.5 ft
	55" + 100-yr SWEL
	3.8 ft
System Responsible (See overview map)	6



Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL

Future Projects
None



Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

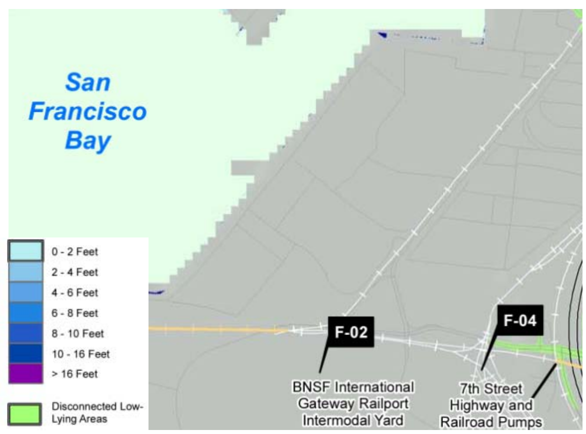
BNSF International Gateway Intermodal Yard (F-02)

Asset Location / Jurisdiction
Oakland / BNSF Railway

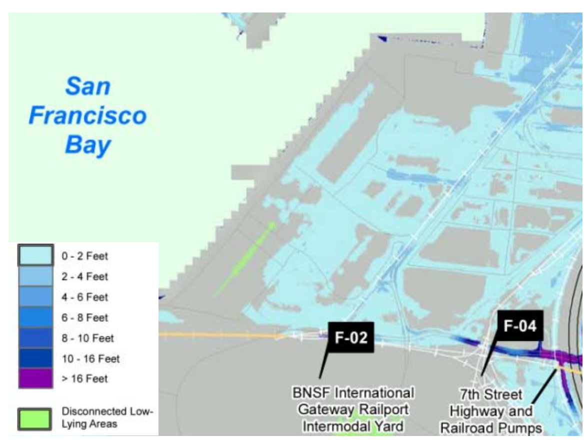
Summary
BNSF Railway operates an intermodal shipping facility at the Port of Oakland, adjoining the Union Pacific Niles Subdivision. Due to lack of data, this asset was not rated with respect to sensitivity. Exposure is rated low, due to inundation under only 100-year SWEL + wind waves for both the 16" and 55" SLR scenarios. When considering that no adequate alternative is available for this asset, vulnerability is rated medium. Consequence is rated high for capital improvement costs, time to rebuild, and goods movement, and low for all other considerations. The overall consequence rating is 3.00, making this a medium-risk asset.

Characteristics:
- At grade
- Goods movement

Sensitivity	
Data unavailable in project timeframe.	
Liquefaction Susceptibility	Very High
Exposure: Low	
Maximum Inundation Depths	
16” + MHHW	0 ft
16” + 100-yr SWEL	0 ft
16” + 100-yr SWEL + wind waves	YES
55” + MHHW	0 ft
55” + 100-yr SWEL	0 ft
55” + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16” SLR): High No adequate alternative available	
Vulnerability Rating (**mid century**)**: Medium**	



Projected Inundation with 16 inch SLR + 100-yr SWEL

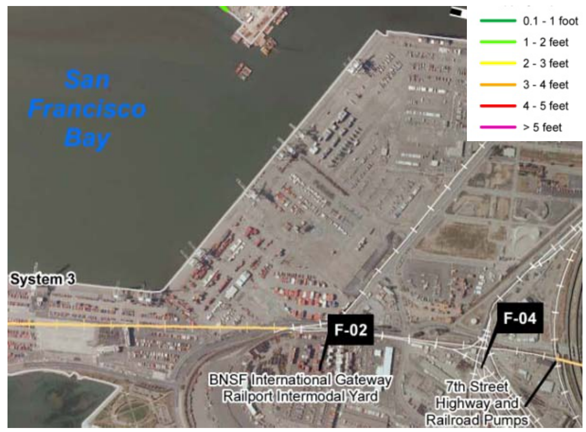


Projected Inundation with 55 inch SLR + 100-yr SWEL

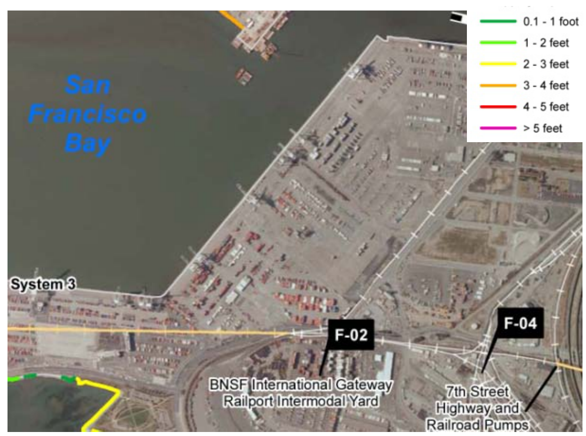
Consequence Rating (out of 5): 3.00	
Capital improvement cost	Likely to cost at least as much as a bus facility (5)
Time to rebuild	Likely at least 5 years (5)
Public safety	Not applicable (1)
Economic impact - goods movement	Crucial to goods movement (5)
Economic impact - commuter route	Not applicable (1)
Socio-economic impact	Transit-Dependent area only (1)
Risk Rating: Medium	

Shoreline Asset “Overtopping” Analysis	
Proximity to Overtopping (distance)	***16” + 100-yr SWEL***
	990 ft
	55” + 100-yr SWEL
	860 ft
Length Overtopped (% of System)	***16” + 100-yr SWEL***
	5,800 ft (12%)
	55” + 100-yr SWEL
	20,780 ft (41%)
Average Depth of Overtopping	***16” + 100-yr SWEL***
	1.4 ft
	55” + 100-yr SWEL
	2.6 ft
System Responsible (See overview map)	3

Future Projects
None



Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



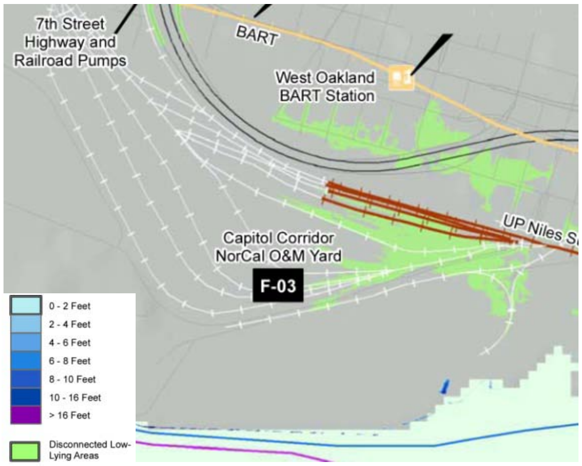
Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

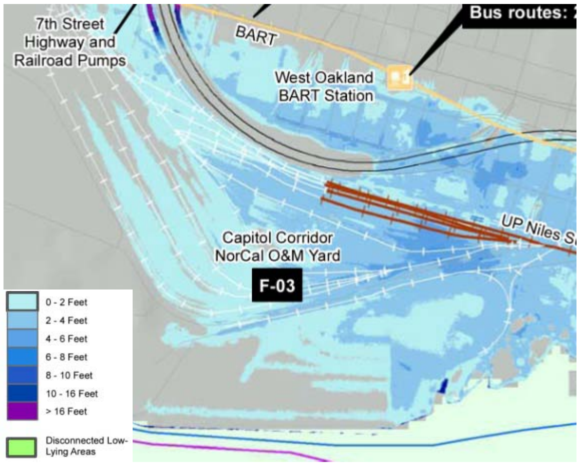
Capitol Corridor Norcal O&M Yard (F-03)

Asset Location / Jurisdiction Oakland / Capitol Corridor JPA
Summary Amtrak Capitol Corridor service is supported by an operations and maintenance facility adjoining the Union Pacific Railroad Niles Subdivision in Oakland. Due to lack of data, this asset was not rated with respect to sensitivity. Exposure is rated medium, due to inundation under the 55" + MHHW SLR scenario. When considering that no adequate alternative is available for this asset, vulnerability is rated medium-high. Consequence is rated high for capital improvement costs, moderate for time to rebuild and commuter use, and low for all other considerations. The overall consequence rating is 2.33, making this a medium-risk asset.
Characteristics: • At grade • Maintenance facility

Sensitivity	
Data unavailable in project timeframe.	
Liquefaction Susceptibility	Very High
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW	0 ft
16" + 100-yr SWEL	0 ft
16" + 100-yr SWEL + wind waves	YES
55" + MHHW	3 ft
55" + 100-yr SWEL	6 ft
55" + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16" SLR): High No adequate alternative available	
Vulnerability Rating (mid century): Medium-High	



Projected Inundation with 16 inch SLR + 100-yr SWEL

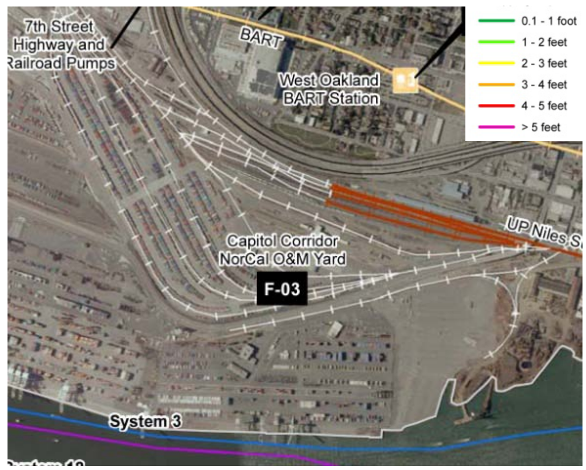


Projected Inundation with 55 inch SLR + 100-yr SWEL

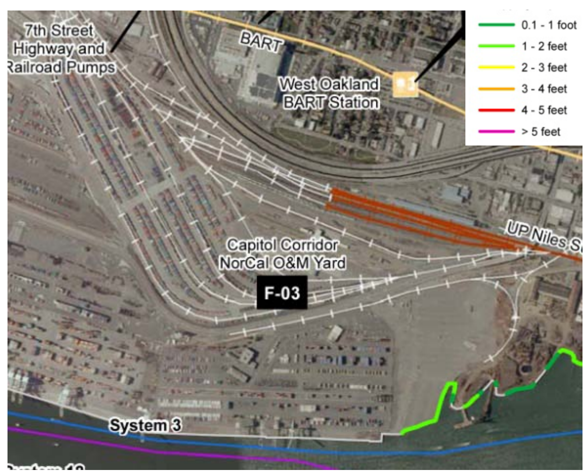
Consequence Rating (out of 5): 2.33	
Capital improvement cost	Likely at least as much as a bus facility (5)
Time to rebuild	Likely within 5 years (3)
Public safety	Minor consequence (1)
Economic impact - goods movement	Not applicable (1)
Economic impact - commuter route	Supports Capitol Corridor service (3)
Socio-economic impact	Community of Concern; supports "Premium" transit (1)
Risk Rating: Medium	

Shoreline Asset "Overtopping" Analysis	
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***
	2,360 ft
	55" + 100-yr SWEL
	1,160 ft
Length Overtopped (% of System)	***16" + 100-yr SWEL***
	5,800 ft (12%)
	55" + 100-yr SWEL
	20,780 ft (41%)
Average Depth of Overtopping	***16" + 100-yr SWEL***
	1.4 ft
	55" + 100-yr SWEL
	2.6 ft
System Responsible (See overview map)	3

Future Projects
None



Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

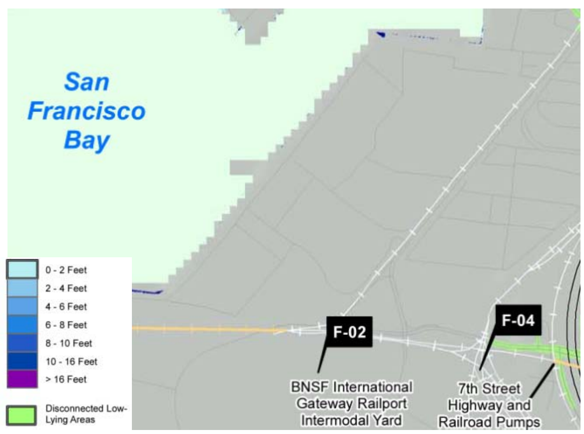
7th Street Highway and Railroad Pumps (F-04)

Asset Location / Jurisdiction
Oakland / Caltrans

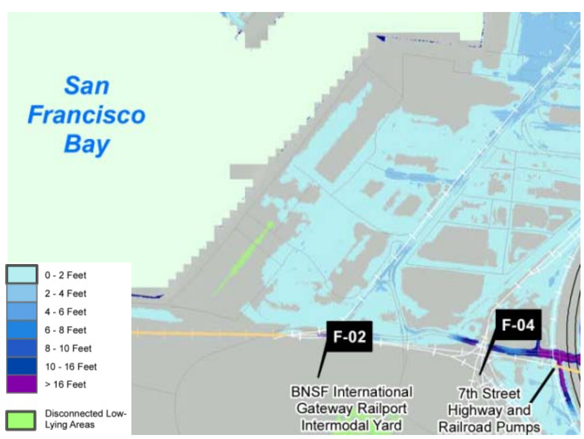
Summary
Caltrans maintains pumping facilities in the vicinity of the 7th Street underpass of I-880 and the Union Pacific Railroad Niles Subdivision. Due to lack of data, this asset was not rated with respect to sensitivity. Exposure is rated low, due to inundation under only 100-year SWEL + wind waves for both the 16" and 55" SLR scenarios. When considering that no adequate alternative is available for this asset, vulnerability is rated medium. Consequence is rated high for goods movement, moderate for commuter use, and low for all other considerations. The overall consequence rating is 2.00, making this a medium-risk asset.

Characteristics:
- At grade
- Maintenance facility

Sensitivity	
Data unavailable in project timeframe.	
Liquefaction Susceptibility	Medium
Exposure: Low	
Maximum Inundation Depths	
16" + MHHW	0 ft
16" + 100-yr SWEL	0 ft
16" + 100-yr SWEL + wind waves	YES
55" + MHHW	0 ft
55" + 100-yr SWEL	0 ft
55" + 100-yr SWEL + wind waves	YES
Inadequate Adaptive Capacity (16" SLR): High No adequate alternative available	
Vulnerability Rating (mid century): Medium	



Projected Inundation with 16 inch SLR + 100-yr SWEL

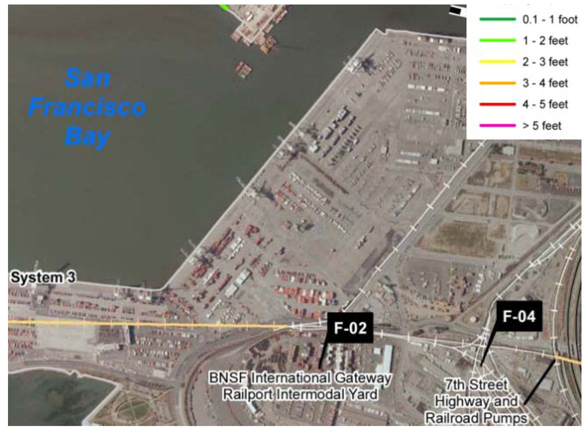


Projected Inundation with 55 inch SLR + 100-yr SWEL

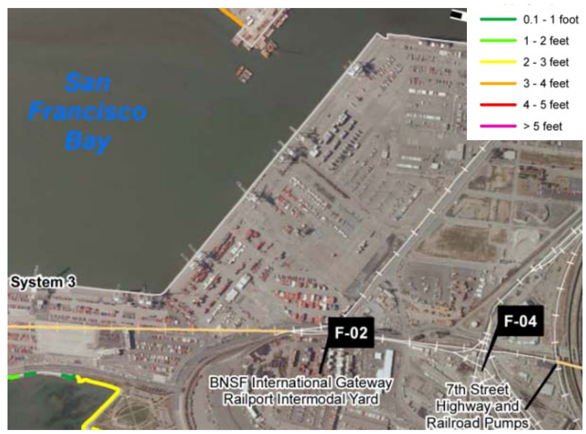
Consequence Rating (out of 5): 2.00	
Capital improvement cost	Likely less than $20 million (no structures of appreciable size) (1)
Time to rebuild	Likely within 2 years (no structures of appreciable size) (1)
Public safety	Minor consequence (1)
Economic impact - goods movement	Supports I-880 and UPRR; both carry high goods volumes (5)
Economic impact - commuter route	Supports I-880 (3)
Socio-economic impact	Community of Concern + Transit Dependent area only (1)
Risk Rating: Medium	

Shoreline Asset "Overtopping" Analysis	
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***
	5,890 ft
	55" + 100-yr SWEL
	5,710 ft
Length Overtopped (% of System)	***16" + 100-yr SWEL***
	5,800 ft (12%)
	55" + 100-yr SWEL
	20,780 ft (41%)
Average Depth of Overtopping	***16" + 100-yr SWEL***
	1.4 ft
	55" + 100-yr SWEL
	2.6 ft
System Responsible (See overview map)	3 May be vulnerable to backdoor flooding from System 2 at higher SLR scenario

Future Projects
None



Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Appendix D – Accompanying Chapter 7 Adaptation Planning

Table D1 How to Use Information Provided In Risk Profile

		EXAMPLE scenarios identified in the risk profiles:	EXAMPLES of adaptation potential for:
Vulnerability	**Exposure**	Temporary inundation, less than 1ft	Drainage improvements; Foundation improvements; waterproofing; demountable flood barrier
		Permanent inundation, less than 1ft	Raising asset
	Sensitivity	Poor condition	Upgrade during next maintenance cycle; raising; new materials; waterproofing
		Not yet seismically retrofitted	Upgrade during retrofit; raising; new materials; waterproofing
		Close to end of service life	Upgrade during replacement; raising; new materials; waterproofing
	Adaptive capacity	Can be rerouted 100% onto another mode or route	Structural measures could be avoided; temporary closure acceptable short term
		Can be partially rerouted	Structural measures could be avoided; temporary closure acceptable short term
Overtopping potential	**% Overtopped**	Low % / short length of system	Raising portion of levee system (smaller scale solution)
		High % / long length of system	New sea wall or other engineered flood protection system; raising levee
	Depth of overtopping	Average depth less than 2 ft	Minor modifications to shoreline might prevent inundation, e.g. small or demountable flood wall or low berm
		Average depth greater than 2ft	Major overhaul of shoreline protection infrastructure may be needed, e.g. new floodwall or levee
	Number of systems involved	Only one system	Maybe a simpler solution; Fewer jurisdictions need to be involved
		More than one system	More jurisdiction involved; more complex solution and planning required; more assets likely to be protected by solution
	Distance from transportation asset	Close to the asset	Fewer adaptation solutions may be possible, limited to moving the asset or building larger flood protection levees
		Far from the asset	Multiple adaptation options possible
Consequence	**Rating**	High	Temporary or partial closure likely unacceptable, raising asset to reduce consequence to be considered, adaptation planning high priority
		Low	Temporary or partial closure might be an option. SLR inundation can still be high and might require significant adaptation to save asset

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