Adapting to Rising Tides

Transportation Vulnerability and Risk Assessment Pilot Project

Technical Report • November 2011

Acknowledgments

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Jack London Square at the end of Broadway during King Tide

"The San Francisco Bay Area is one of the most economically and ecologically vibrant regions in the world. But it is also critically vulnerable to the impacts of climate change. As a region, it is imperative that we adapt to the impacts of climate change by fostering resilient and sustainable development. This challenge brings us an exciting opportunity to embrace a spirit of stewardship that advances both economic and environmental prosperity." *—Will Travis, Executive Director, BCDC*

TABLE OF CONTENTS

Section Page

Acronyms and Abbreviations ... iv

1 Introduction ... 1-1

1.1 Background ... 1-1

1.1.1 Adapting To Rising Tides Project and Federal Highway Administration Pilot Project ... 1-1

1.1.2 Pilot Project Area ... 1-1

1.2 Parties Involved ... 1-4

1.2.1 Project Team – Roles and Responsibilities ... 1-4

1.2.2 Stakeholders ... 1-4

1.3 Overview of FHWA Pilot Process ... 1-5

1.4 Structure of the Report ... 1-7

1.5 References ... 1-7

2 Asset Inventory Development and Asset Selection ... 2-1

2.1 Introduction ... 2-1

2.2 Asset Inventory Development ... 2-3

2.2.1 Initial Transportation Asset Inventory Data Collection ... 2-3

2.2.2 Initial Shoreline Asset Inventory Data Collection ... 2-3

2.2.3 Initial Data Received for Transportation and Shoreline Assets ... 2-5

2.2.4 Identification of Asset Categories and Asset Types ... 2-5

2.3 Transportation Asset Selection Methodology ... 2-5

2.3.1 Functionality and Other Characteristics to Select Representative Assets ... 2-9

2.4 Shoreline Asset Categorization ... 2-13

2.4.1 Engineered Flood Protection Structures ... 2-15

2.4.2 Engineered Shoreline Protection Structures ... 2-17

2.4.3 Nonengineered Berm ... 2-21

2.4.4 Wetlands ... 2-22

2.4.5 Natural Shoreline (Nonwetland) ... 2-24

2.4.6 Shoreline Categorization Maps ... 2-27

2.5 Recommended Refinements to the FHWA Conceptual Model ... 2-30

2.5.1 Data Collection and Synthesis Issues ... 2-30

2.5.2 Lessons Learned ... 2-30

2.5.3 Recommendations for Future Applications ... 2-31

2.6 References ... 2-31

3 Seismic Vulnerability Assessment ... 3-1

3.1 Introduction ... 3-1

3.2 Current Geotechnical/Seismic Hazard Conditions ... 3-2

3.2.1 Soft/Weak Soils/Fill ... 3-2

3.2.2 Ground Shaking Potential ... 3-2

3.2.3 Liquefaction Potential ... 3-6

3.2.4 Groundwater ... 3-6

3.3 Seismic Vulnerability from SLR Direct Inundation and Indirect Groundwater Rise ... 3-8

3.3.1 Incremental Seismic Impact/Failure Risk to Shoreline Assets from SLR ... 3-8

3.3.2 Incremental Seismic Impact/Failure Risk to Transportation Assets from SLR ... 3-10

3.4 Recommended Refinements to the FHWA Conceptual Model ... 3-11

3.4.1 Lessons Learned ... 3-11

3.5 References ... 3-11

4 Climate Science and Climate Impacts 4-1
4.1 Introduction 4-1
4.2 Climate Information Summary 4-2
4.3 Inundation Mapping 4-3
4.3.1 Inundation Maps 4-3
4.3.2 Shoreline Overtopping Potential 4-4
4.3.3 Transportation Asset Inundation Potential 4-5
4.3.4 Underlying Assumptions and Caveats 4-5
4.4 Recommended Refinements to the FHWA Conceptual Model 4-6
4.4.1 Climate Science Data Gathering 4-6
4.4.2 Lessons Learned 4-7
4.4.3 Recommendations 4-7
4.5 References 4-8

5 Vulnerability and Risk Assessment 5-1
5.1 Introduction 5-1
5.2 Vulnerability Assessment 5-1
5.2.1 Introduction 5-1
5.2.2 Exposure to SLR 5-3
5.2.3 Sensitivity 5-4
5.2.4 Adaptive Capacity 5-6
5.2.5 Overall Vulnerability Assessment 5-8
5.3 Risk Assessment 5-9
5.3.1 Introduction 5-9
Selection of Assets for Risk Assessment 5-11
5.3.2 Likelihood 5-12
5.3.3 Consequence 5-13
5.4 Risk Profiles 5-15
5.4.1 Introduction 5-15
5.5 Recommended Refinements to the FHWA Conceptual Model 5-20
5.5.1 Lessons Learned 5-20
5.5.2 Recommendations for future applications 5-21
5.6 References 5-22

6 Sea Level Rise Maps 6-1
6.1 Introduction 6-1
6.2 Caveats Associated with the Maps 6-1
6.3 Inundation Overview Maps 6-5
6.4 Inundation Zoom-In Maps Showing Selected Transportation Asset Location 6-13
6.5 Maps Showing Depths of Shoreline Systems Overtopped 6-45
6.6 Maps Showing Percentages of Shoreline Systems Overtopped 6-49
6.7 Overtopping Depth Zoom-In Maps Showing the Selected Transportation Asset Locations6-53

7 Adaptation Planning 7-1
7.1 Introduction 7-1
7.2 Climate Change Adaptation Measures 7-1
7.3 Methodology to Analyze and Use Risk Profiles for Adaptation Planning 7-6
7.3.1 Evaluation of Risk Profiles 7-6
7.3.2 use of evaluation criteria 7-7
7.4 Example Assets 7-9
7.4.1 San Francisco–Oakland Bay Bridge 7-9
7.4.2 Oakland Jack London Square Amtrak Station 7-13
7.4.3 Nonstructural Regional Adaptation Measures 7-15

7.5 Next Steps in Adaptation Planning 7-17
7.6 References 7-17

Appendices

A Asset Inventory Development and Asset Selection
B Climate Science and Climate Impacts
C Vulnerability and Risk Assessment

TABLE OF CONTENTS

Continued Page

Figures

Figure 1.2 Project Area and Inundation Extent 1-3
Figure 1.3 Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Process... 1-6
Figure 2.1 Asset Inventory and Selection Process........ 2-2
Figure 2.2 GIS Data Available - Example for Bike Lanes and the Bay Trail........ 2-6
Figure 2.3 Location of Shoreline Asset Examples 2-15
Figure 2.4 Engineered Levee with Revetment: Oakland International Airport, Oakland; Roadway Is Levee Crest........ 2-16
Figure 2.5 Schematic of Levee Cross Section........ 2-17
Figure 2.6 Flood Wall: Eden Shores, Landward of Eden Landing Complex, Hayward (Nonengineered Berm also Pictured to the Right of the Floodwall with Roadway as Berm Crest)........ 2-17
Figure 2.7 Bulkhead, Port of Oakland, Oakland........ 2-18
Figure 2.8 Revetment, Shoreline Park, Alameda........ 2-19
Figure 2.9 Revetment, Port of Oakland, Oakland 2-19
Figure 2.10 Nonengineered Berm with Riprap Protection, Hayward; Roadway Berm Is Berm Crest..... 2-20
Figure 2.11 Riprap Protection for Wastewater Treatment Plant, San Leandro (Wetlands and Tidal Flats Outboard) 2-20
Figure 2.12 Maintenance of a Nonengineered Berm in Eden Landing by the Mallard, Hayward........ 2-21
Figure 2.13 Former Salt Pond Berm, Hayward (with Outboard Tidal Flats)........ 2-22
Figure 2.14 Nonengineered Berm with Riprap-Protecting Tidal Marsh from Wave Erosion, Hayward (see Hayward Marsh Figure 2.17 below under “Wetlands”) 2-23
Figure 2.15 Wetlands with Natural Marsh Edge, Emeryville........ 2-23
Figure 2.16 San Lorenzo Creek Tidal Flats, San Leandro (Some Inland Areas Have Riprap-Armored Shoreline; see Figure 2.21)........ 2-24
Figure 2.17 Managed Wetlands, Hayward (Protected Tidal Marsh, Managed Marsh, Managed Ponds – Extensive Nonengineered Berm Networks) 2-25
Figure 2.18 Whales Tail Marsh, Eden Landing, Hayward 2-25
Figure 2.19 Beach – Robert Crown Memorial State Beach, Alameda (Beach Is Erosional and Maintained through Beach Nourishment [i.e., Imported Sand]) 2-26
Figure 2.20 Beach – Robert Crown Memorial State Beach, Alameda (Steep Sand Dunes Lead to Bicycle Trail and Roadway)........ 2-26
Figure 2.21 Shoreline Categorization Map – Northern Extent........ 2-28
Figure 2.22 Shoreline Categorization Map – Southern Extent........ 2-29
Figure 3.1 Seismic Vulnerability Assessment Process........ 3-1
Figure 3.2 Historical Baylands 3-3
Figure 3.3 Modern Baylands........ 3-4
Figure 3.4 Shaking Severity........ 3-5
Figure 3.5 Liquefaction Susceptibility........ 3-7
Figure 3.6 Force on Foundation Due to Lateral Spreading 3-9
Figure 3.7 Slope Failure Due to Lateral Spreading........ 3-9
Figure 4.1 Climate Science and Climate Impacts Process........ 4-1
Figure 5.1 Vulnerability and Risk Assessment Process 5-2

Figure 5.2 Risk Rating Matrix 5-16
Figure 5.3 Risk Profile Glossary: Asset Name (Asset Code) 5-19
Figure 7.1 Levee Construction 7-4
Figure 7.2 Freeway On Top Of A Levee 7-4
Figure 7.3 Rendering Of Levee Placed Out Into The Bay And Wetland Development Inboard of The Levee 7-4
Figure 7.4 Demountable Floodwall Along Urban Waterfront 7-5
Figure 7.5 Glass Wave Overtopping Wall On A Levee 7-5
Figure 7.6 Raising Of Existing Levee 7-5
Figure 7.7 Residential Development As Flood Protection Barrier 7-6
Figure 7.8 Artist Impression Of Levee Combined With Urban Functions 7-6

TABLE OF CONTENTS

Continued Page

Tables

Table 2.1 Transportation Asset Types Identified for the Subregion 2-3
Table 2.2 Transportation Stressors / Asset Information 2-4
Table 2.3 Transportation Asset Importance - Evaluation and Prioritization Criteria 2-4
Table 2.4 Potential Shoreline Protection Asset Types and Data Sources........ 2-4
Table 2.5 Asset Type Definitions........ 2-7
Table 2.6 Functionalities and Characteristics of Transportation Assets........ 2-10
Table 2.7 Stressor or “Sensitivity” Criteria 2-13
Table 4.1 SLR Projections Using 2000 as the Baseline 4-2
Table 5.1 Midcentury Exposure Rating 5-3
Table 5.2 End-of-Century Exposure Rating........ 5-4
Table 5.3 Sensitivity Rating – Interstates/Freeways and State Routes........ 5-5
Table 5.4 Sensitivity Rating – Arterials, Collectors, and Local Streets........ 5-6
Table 5.5 Adaptive Capacity 5-7
Table 5.6 Overall Vulnerability Assessment Method 5-8
Table 5.7 Vulnerability Assessment Method Applied to Select Assets 5-9
Table 5.8 Likelihood Rating 5-13
Table 5.9 Consequence Criteria........ 5-14
Table 5.10 Example Consequence Rating 5-15
Table 5.11 Final List of Risk Profiles, by Asset Category and Asset Type, Showing Final Risk Rating . 5-16
Table 6.1 Number of maps produced by type........ 6-1
Table 7.1 Potential Adaptation Measures Applicable to Alameda County 7-2
Table 7.2 Criteria for Helping Selection of Adaptation Measures 7-8
Table 7.3 Suggested Potential Adaptation Strategies for the San Francisco-Oakland Bay Bridge........ 7-10
Table 7.4 Potential Suggested Adaptation Strategies for the Oakland Jack London Square Amtrak Station7-14

ACRONYMS AND ABBREVIATIONS

AADT	Annual Average Daily Traffic
AADTT	Annual Average Daily Truck Traffic
AAWDT	Annual Average Weekday Daily Traffic
ABAG	Association of Bay Area Governments
AC Transit	Alameda-Contra Costa Transit District
ACFCWCD	Alameda County Flood Control and Water Conservation District
ACTC	Alameda County Transportation Commission
ACPWA	Alameda County Public Works Agency
ADT	Average Daily Traffic
AOGCMs	Atmosphere-Ocean General Circulation Models
ART	Adapting to Rising Tides
BAARI	Bay Area Aquatic Resource Inventory
BART	Bay Area Rapid Transit
BCDC	San Francisco Bay Conservation and Development Commission
CA	California
Caltrans	California Department of Transportation, District 4
C-CAP	Coastal Change Analysis Program
CC	MTC Communities of Concern
CCSM3	Community Climate System Model Version 3
CDC	California Department of Conservation
CO_2	Carbon Dioxide
CO-CAT	Coastal and Ocean Working Group for the Climate Action Team
CT	Consultant Team
CTC	Alameda County Transportation Commission
DEM	Digital Elevation Model
DFG	California Department of Fish and Game
DPW	Alameda County Department of Public Works
DOT	Department of Transportation
EMIC	Earth System Models of Intermediate Complexity
EBRPD	East Bay Regional Park District
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
GHG	Greenhouse Gases
GIS	Geographic Information System
HARD	Hayward Area Recreation and Park District
HOV	High-Occupancy Vehicle
I-	Interstate
ICE	Intermodal Corridors of Economic Significance

IPCC	Intergovernmental Panel on Climate Change
IRRS	Interregional Road System
ITS	Intelligent Transportation Systems
HD	Hydrodynamic
JPA	Capitol Corridor Joint Powers Authority
LOS	Level of use / service
LIDAR	Light Detection and Ranging
MHHW	Mean High Higher Water
MLLW	Mean Lower Low Water
MPO	Metropolitan Planning Organization
MTC	Metropolitan Transportation Commission
MTC-RTCI	Metropolitan Transportation Commission – Regional Transit Capital Inventory
MTL	Mean Tidal Level
NAVD	North American Vertical Datum
NOAA CSC	National Oceanic and Atmospheric Administration Coastal Services Center
O&M	Operations and Maintenance
OPC	California Ocean Protection Council
PMT	Project Management Team (MTC, BCDC, Caltrans)
QA/QC	Quality Assurance/Quality Control
SCC	California State Coastal Conservancy
SCM	Simple Climate Models
SFEI	San Francisco Estuary Institute
SLR	Sea level rise
SR	State Route
SRES	IPCC Special Report on Emissions Scenarios
STAA	Surface Transportation Assistance Act
STRAHNET	Strategic Highway Network
SW	Spectral Wave
SWEL	Stillwater Elevation
TANA	TeleAtlas North America
TD	Transit Dependent
UPRR	Union Pacific Railroad
USACE	U.S. Army Corps of Engineers
USGS	United States Geographical Survey
WETA	Water Emergency Authority
WWTP	Waste Water Treatment Plant

Introduction 1.0

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1 Introduction

1.1 Background

1.1.1 ADAPTING TO RISING TIDES PROJECT AND FEDERAL HIGHWAY ADMINISTRATION PILOT PROJECT

The San Francisco Bay Conservation and Development Commission (BCDC) has partnered with the National Oceanic and Atmospheric Administration Coastal Services Center to work with San Francisco Bay Area shoreline communities on planning for sea level rise (SLR) and other climate change–related impacts. The overall goal of the project, called Adapting to Rising Tides (ART), is to increase the preparedness and resilience of Bay Area communities to SLR and other climate change–related impacts while protecting ecosystem and community services. It involves evaluating potential shoreline impacts, vulnerabilities, and risks; identifying effective adaptation strategies; and developing and refining adaptation planning tools and resources that will be useful to communities throughout the Bay Area.

As part of the project, the Metropolitan Transportation Commission (MTC), California Department of Transportation District 4 (Caltrans), and BCDC collaborated on a subregional planning pilot project to test the conceptual Risk Assessment model developed by the Federal Highway Administration (FHWA) to assess the climate change–related SLR risks to transportation infrastructure in a select portion of the San Francisco Bay Area.

The purpose of the pilot project is to enable the region's transportation planners, including those at the MTC, Caltrans, congestion management agencies, and local governments, to improve vulnerability and risk assessment practices and to help craft effective adaptation strategies. If both existing and planned transportation infrastructure is assessed, vital infrastructure can be protected, and future investments can be guided by the best available information about future climate and SLR conditions.

In a project called Living with a Rising Bay that was completed in 2009, BCDC analyzed SLR-related impacts and vulnerabilities for the entire San Francisco Bay and its shoreline and identified broad solutions to these issues. The scale of the analysis was too large, however, to allow localized shoreline issues to be examined or specific strategies addressing these issues to be developed. One of the goals of the FHWA pilot project is to develop an approach for more fine-grained vulnerability assessments and planning efforts.

1.1.2 PILOT PROJECT AREA

The nine-county San Francisco Bay Area, home to approximately 7 million people, is the nation's fifth most populated metropolitan or urbanized area. Its economy, culture, and landscape—supporting prosperous businesses, vibrant neighborhoods, and productive ecosystems—are linked with a vital system of public infrastructure, including freeways, seaports, railroads, and airports, local roads, mass transit, and bicycle and pedestrian facilities that connects the shoreline communities to each other and to the rest of the region, the state, the nation, and the world.

According to current projections, climate change will cause the Bay to rise 16 inches by midcentury and 55 inches by the end of the century (CO-CAT 2010). This means that today's floods will be the future's high tides and areas that currently flood every 10–20 years will flood much more frequently. Neighborhoods, businesses, and entire industries that currently exist on the shoreline will be subject to this flooding and the many other direct impacts that will result from it. These areas are home to more than 250,000 residents who will be directly affected and many others, including workers, who will be indirectly affected by reduced access to important services, such as transit and commercial centers, health-care facilities, and schools. Figure 1.1 shows inundation of the roadway adjacent to the Bay Bridge Toll Plaza during the King Tide in February 2011, an extreme high tide event that provided a snapshot of the inundation that could occur with potential future sea level rise in the Bay Area.

After a competitive process the Alameda County shoreline (stretching from Emeryville in the north to Union City in the south) was selected as the subregion of the Bay Area to be assessed for the FHWA pilot project. Five subregions originally expressed interested in participating in the project. The Alameda County subregion provided the most comprehensive submittal and included interest from the cities of Oakland, San Leandro, Hayward and San Lorenzo, the county, East Bay Regional Park District, Bay Trail and other partners. The shoreline of the subregion is diverse including airports, seaports, industrial, residential, parks and natural systems. The subregion also contains a large amount of regionally significant transportation infrastructure including rail, highways, two bridge touchdowns, the Oakland International airport and port and Bay Area Rapid Transit (BART). This selection process ensured the pilot project had committed and interested stakeholders from the beginning.

Figure 1.2 shows the project area and the inundation extent under both the 16-inch and 55-inch SLR scenarios.

Photo used under Creative Commons, provided by Flickr user Mark Songey.

Figure 1.1 Inundation from the 2011 King Tide

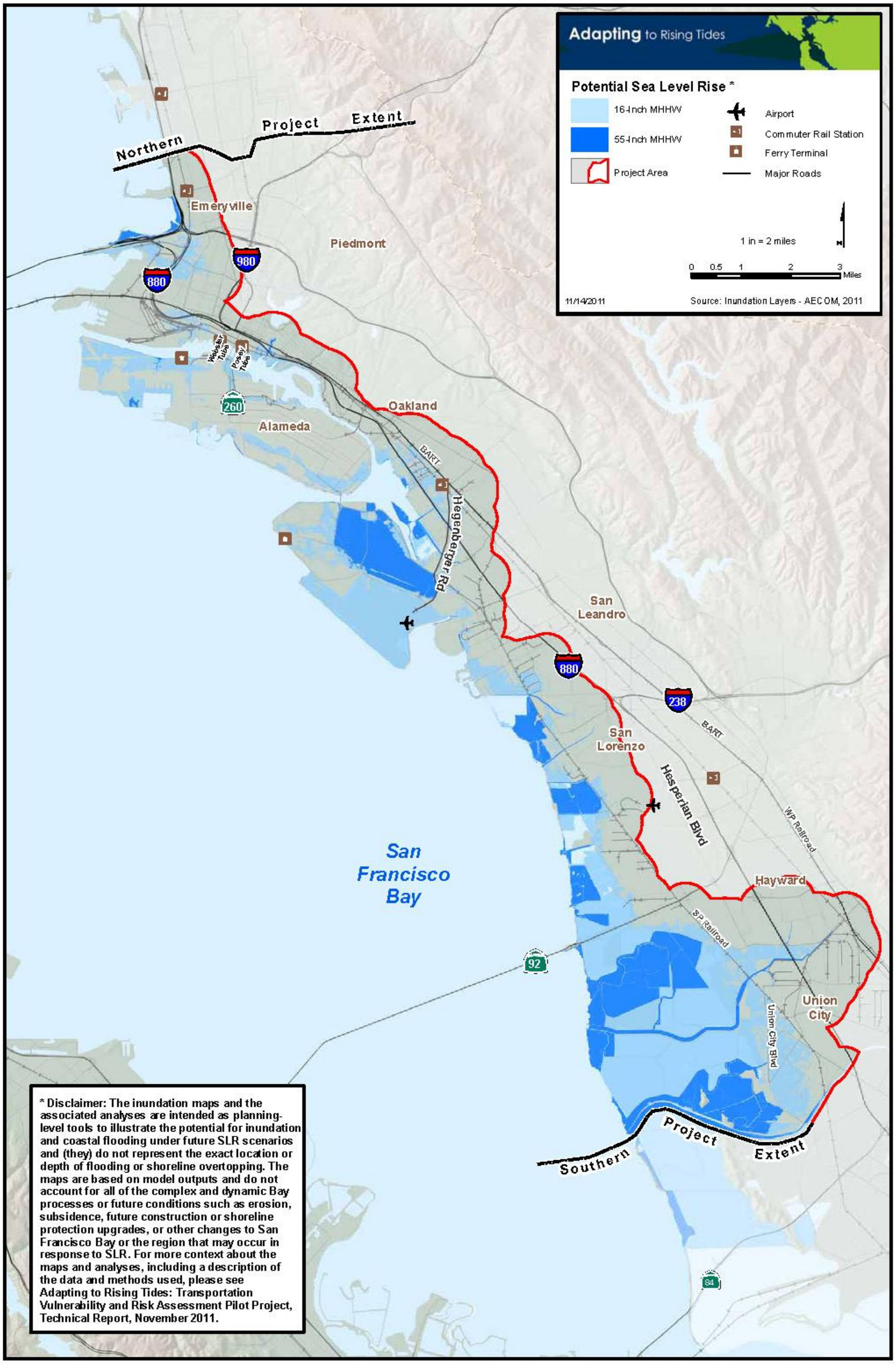

Figure 1.2 Project Area and Inundation Extent

1.2 Parties Involved

1.2.1 PROJECT TEAM – ROLES AND RESPONSIBILITIES

PROJECT MANAGEMENT TEAM

The Project Management Team (PMT) consisted of representatives from MTC, Caltrans, and BCDC. The PMT provided review of and guidance for the pilot project and supported the Consultant Team (CT) (described in the following section) by obtaining data from their own departments and from local stakeholders. MTC and Caltrans led the identification and assessment of transportation assets, and BCDC led the effort of assembling the information on shoreline assets, climate science, and SLR. BCDC is also leading the ART project and thus provided additional input and guidance on methodology and project process to the team.

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

Caltrans is responsible for designing, constructing, maintaining, and operating the California highway system and the portion of the interstate highway system in the Bay Area. Caltrans released its own guidance (Caltrans 2011) on how to incorporate SLR into planning documents in May 2011 (during the life of this project) and is interested in understanding how to plan for the risks associated with climate change.

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

CONSULTANT TEAM

The Consultant Team (CT) was composed of transportation planners and engineers, environmental planners, and coastal engineering specialists from AECOM Technical Services and its subconsultants for this project: ARCADIS, Geografika, and 3-D Visions. Note that references to the "project team" include both the PMT and CT.

1.2.2 STAKEHOLDERS

TRANSPORTATION AND SHORELINE ASSET SUBCOMMITTEES

The ART project stakeholder group was a valuable resource and sounding board for the FHWA pilot project. For the purposes of the pilot project, the group was organized into Transportation and Shoreline Asset Subcommittees.

The Transportation Asset Subcommittee included representatives from Caltrans, MTC, BART, BCDC, Capitol Corridor Joint Powers Authority, Association of Bay Area Governments, Alameda County Transportation Commission, AC Transit, Port of Oakland, City of Oakland, City of Hayward, City of Union

City, and Water Emergency Transportation Authority. This committee met three times during the course of the project to:

- Assist with data inventory development (see Chapter 2),
- Help select representative transportation assets (see Chapter 2), and
- Review consequence criteria and ratings of the selected assets (see Chapter 5).

The Shoreline Asset Subcommittee included representatives from the Alameda County Flood Control and Water Conservation District, Alameda County Public Works Agency, BCDC, California Department of Fish and Game, California State Coastal Conservancy, San Francisco Estuary Institute, U.S. Geological Survey, and U.S. Army Corps of Engineers.

This committee met twice during the course of the project to:

- Assist with data inventory development (see Chapter 2), and review climate science and related stressor information (see Chapter 4), and
- Review consequence criteria and ratings of the selected assets (see Chapter 5).

ART SUBREGION WORKING GROUP

The ART project holds regular Subregion Working Group meetings to allow for public input. At these meetings (three were held during the duration of the FHWA pilot project), progress on the FHWA pilot project was reported, and feedback was sought where appropriate. For example, shoreline and transportation assets were discussed as critical categories for analysis as part of the larger ART effort.

1.3 Overview of FHWA Pilot Process

The goal of the FHWA conceptual Risk Assessment model[1] is to help transportation decision makers (particularly transportation planners, asset managers, and system operators) identify which of their assets are most exposed to the threats from climate change and/or are associated with the most serious potential consequences of those threats.

The Bay Area pilot project is one of five pilot projects being carried out across the country. The other four address:

- Coastal and central New Jersey (New Jersey Department of Transportation [DOT]/North Jersey Transportation Planning Authority),
- Hampton Roads (Virginia DOT),
- State of Washington (Washington State DOT), and
- Island of Oahu (Oahu Metropolitan Planning Organization).

The purpose of the pilot projects is twofold: (1) to assist state DOTs and MPOs in more quickly advancing existing adaptation assessment activities and (2) to assist FHWA in ”test-driving” the model. Based on the feedback received through the pilots, FHWA will revise and finalize the model for national application. The conceptual model consists of three primary components:

1. Develop inventory of assets.
2. Gather climate information.
3. Assess the risk to assets and the transportation system as a whole from projected climate change.

[1] Full details of the model can be accessed here: http://www.fhwa.dot.gov/hep/climate/conceptual_ model62410.htm.

The first two components can be considered simultaneously and are used to identify (a) which assets are important to the transportation system and (b) which climate variables are likely to occur and/or which variables could experience a high-magnitude change. The third component combines the results of the first two to assess how climate changes could affect each important asset and how significant those impacts could be.

During the FHWA pilot project, the CT revised and updated this process because the methodology suitable for the Alameda County subregion context evolved over the lifetime of the project. The updated process for the pilot project is outlined in Figure 1.3.

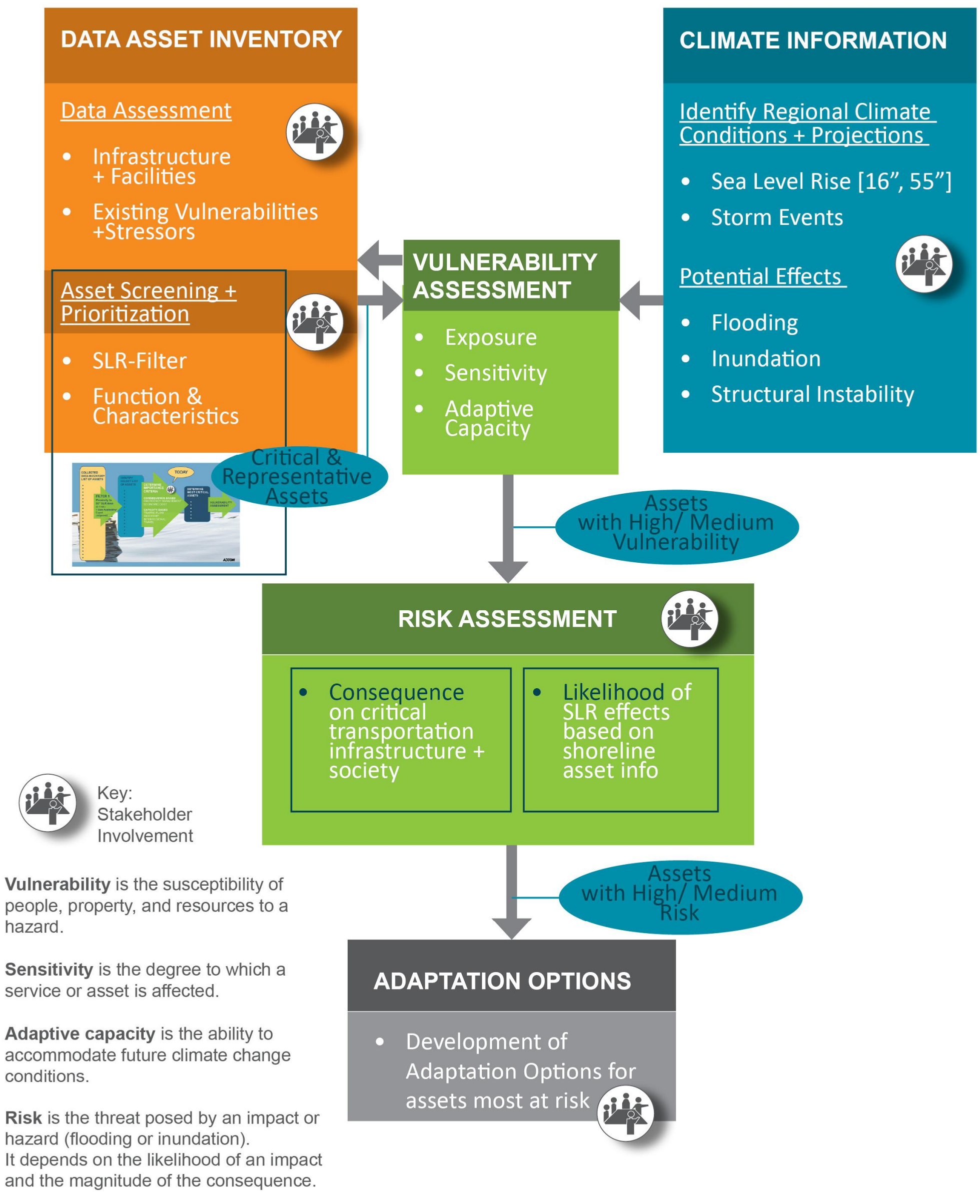

Figure 1.3 Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Process

Note: This process is adapted from FHWA conceptual risk assessment model which was tested through this pilot process.

1.4 Structure of the Report

This technical report documents the full project process. It is accompanied by a briefing book that summarizes key elements of the project for a more general reader. The remainder of the report is structured as follows, with lessons learned and recommendations for the FHWA on the pilot model integrated into relevant chapters:

- Chapter 2, “Asset Inventory Development and Asset Selection,” describes the process of developing an asset inventory and collecting relevant data on transportation and shoreline assets, as well as the process of selecting assets for future analysis.
- Chapter 3, “Seismic Vulnerability Assessment,” describes the seismic vulnerabilities and risk for transportation facilities in the project area from ground shaking and liquefaction of unconsolidated soils and the effect that SLR will have on this seismic risk.
- Chapter 4, “Climate Science and Climate Impacts,” describes the climate science and climate impacts for the subregion, as well as the detailed inundation mapping and overtopping analysis carried out for the shoreline assets.
- Chapter 5, “Vulnerability and Risk Assessment,” describes the vulnerability assessment and risk assessment of the assets identified in Chapter 2. This chapter also includes risk profiles of the selected assets, summarizing the vulnerability and risk-related information gathered.
- Chapter 6, “Sea Level Rise Maps,” contains the detailed inundation and overtopping maps created especially for the project (as a potential separate pullout).
- Chapter 7, “Potential Adaptation Approach,” describes a suggested methodology on how to use the information from the risk profiles to determine what type of adaptation measures can be used to address the vulnerability of transportation assets. It includes, as an example, descriptions of the methodology used to assess impacts, potential adaptation measures, and nonphysical aspects of climate adaptation for two selected transportation assets.

The appendix contains more detailed technical information, including the results of the data inventory, lists of transportation assets, and a description of the mapping methodology.

1.5 References

State of California Sea-Level Rise Interim Guidance Document (CO-CAT 2010)

Guidance on Incorporating Sea Level Rise: For Use in the Planning and Development of Project Initiation Documents; Prepared by the Caltrans Climate Change Workgroup, and the HQ Divisions of Transportation Planning, Design, and Environmental Analysis; May 16, 2011

FHWA Transportation Risk Assessment Model: http://www.fhwa.dot.gov/hep/climate/conceptual_model62410.htm

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Asset Inventory Development and Asset Selection

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2 Asset Inventory Development and Asset Selection

2.1 Introduction

The first step of the Federal Highway Administration (FHWA) conceptual model is to compile an inventory of all transportation assets that are to be evaluated. Example asset categories are provided by the FHWA conceptual model to assist in this task, with a suggested focus on the categories that correspond with the region's planning priorities. While the inventory is being compiled, information is also collected to help evaluate how resilient the asset is to climate stressors and how costly damage to the asset could be. Existing agency inventories of assets are suggested as the primary source of this information.

The second step of the FHWA model process is to "screen" the asset inventory based on the relative importance of each asset. Using existing priorities and metrics (such as volume of use, movement of goods, number of commuters, use as emergency route) the most important assets are identified for the region.

During this initial data collection and inventory development process, it became clear that due to a lack of readily available data in an accessible format and the extensive number of transportation assets in the selected region, an alternative approach would be required. This led to the iterative data collection and asset selection process described in this chapter rather than a sequential process of data collection followed by asset selection as described by the FHWA model. The data collection process in particular evolved to occur in phases, as follows:

1. Initial data collection for the larger subregion consisting mostly of geographic information system (GIS) and spatial data with some metadata,
2. Data regarding functionality and other characteristics collected to assist with selecting representative assets, and
3. Detailed stressor information collected following the selection of representative assets.

The approach for the shoreline assets was different from that used for the transportation assets since it was never the intention to conduct a full vulnerability assessment of the shoreline. The approach evolved to focus on the categorization of the shoreline assets and to use the elevation of these shoreline assets, coupled with the inundation maps (see Chapter 4) to assess which shoreline assets contributed to the inundation of the transportation assets over time.

Section 2.2 describes development of the asset inventory, including the data collection process and approach, a summary of information available and identified data gaps, and includes the data inventory that helped build the asset Inventory. Section 2.3 addresses the steps taken to select the assets for further analysis and subsequent data collection for these assets. Section 2.5 discusses insights on following the FHWA conceptual model and recommendations on refining the process.

Appendix A presents additional tables to support the following discussion, including more detailed versions of some of the tables provided in this chapter.

This process is summarized in Figure 2.1.

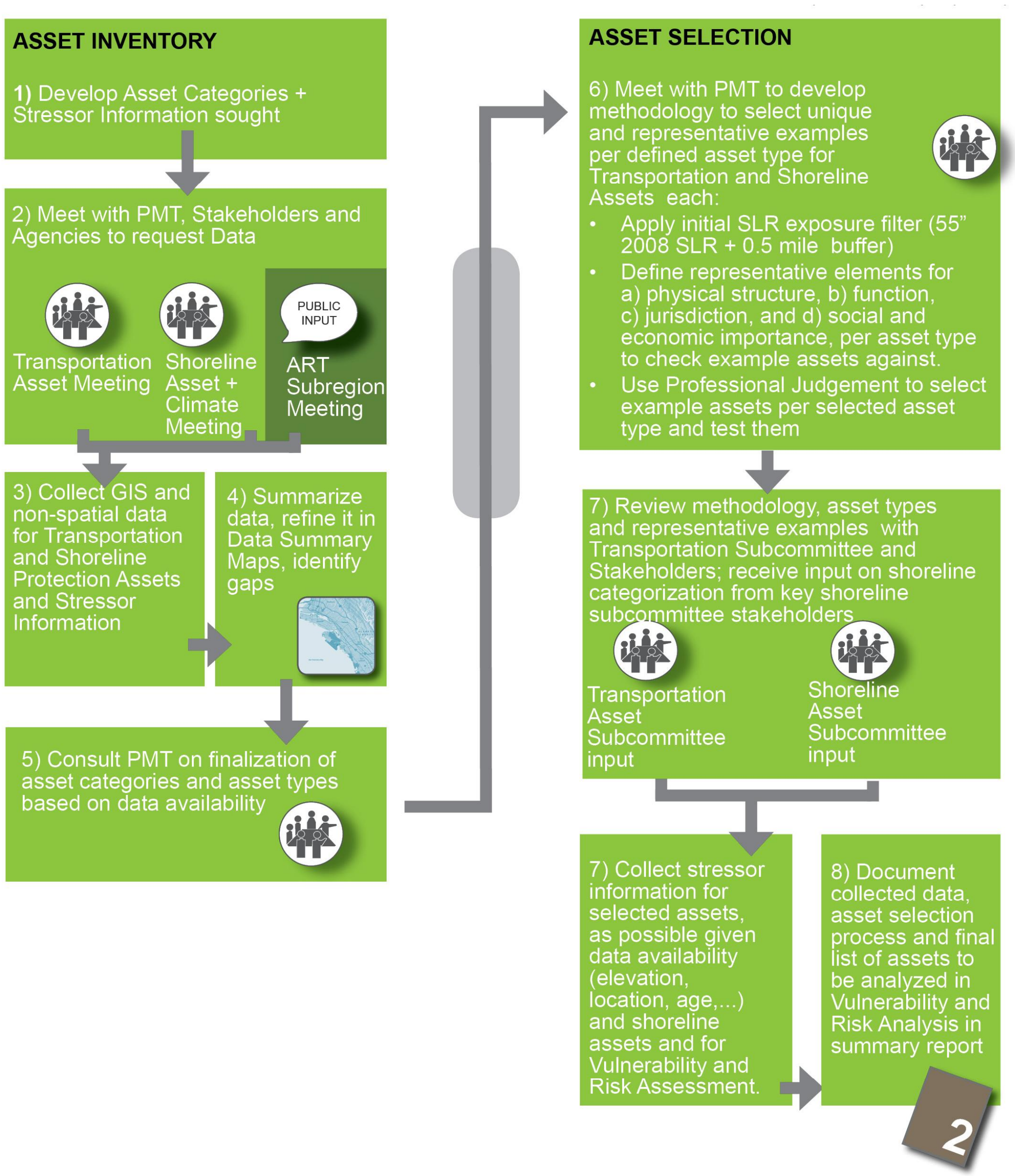

Figure 2.1 Asset Inventory and Selection Process

2.2 Asset Inventory Development

2.2.1 INITIAL TRANSPORTATION ASSET INVENTORY DATA COLLECTION

An initial list of asset types and attributes was developed based on the list suggested by the FHWA model and then expanded based on discussions with the Project Management Team (PMT) (Table 2.1). Stakeholder input was considered vital for identifying the most appropriate list of asset types and for robust data collection. At a meeting with the Transportation Asset Subcommittee, each agency or department provided information on its existing datasets related to each of the transportation asset types selected for the project. Lists of data needs guided the discussion on asset types, data types, and data sources Table 2.2). In addition, the team attempted to look ahead to gathering information to support the development of evaluation and prioritization criteria for the asset prioritization task (Table 2.3). During discussions with the Transportation Asset Subcommittee, it became apparent that detailed stressor information (Table 2.2) was not readily available for the majority of assets in the subregion, which led to focusing the initial data exercise largely on spatial information. This also prompted the decision to reduce the number of assets to be analyzed before requesting stressor information needed for the vulnerability assessment. See Tables A2.1 and A2.2 in Appendix A to see what type of information was available by agency for the asset types.

Table 2.1 Transportation Asset Types Identified for the Subregion

FHWA-Suggested Example Transportation Asset Categories	Transportation Asset Types Considered for the Selected Subregion by Transportation Asset Subcommittee and Project Management Team
Bridges and tunnels	Bridges
	Tunnels and tubes
Key road segments	Highways and state routes
Rail (passenger and freight)	Rail – passenger and freight
Transit system assets	Transit system assets (stations, yards)
Port and airport assets	*Not included in the pilot project*
Signals and traffic control centers	Signals and traffic control centers
Back-up power, communication, fueling, and other emergency operations systems	Emergency operations systems, communication
Intelligent Transportation Systems (ITSs), signs	ITSs
Pipelines	*Not included in the pilot project*
Evacuation routes	Lifeline routes; Evacuation routes for Oakland and other local jurisdictions
	Bike lanes and routes
	Designated truck routes
	Drainage systems associated with transportation assets
	Local streets and roads (assume these include sidewalks)
	Trails

2.2.2 INITIAL SHORELINE ASSET INVENTORY DATA COLLECTION

Similar to the transportation asset data collection exercise, a list identifying desired shoreline asset attribute information was developed to inform the asset discussion with the Shoreline Asset Subcommittee. The FHWA guidance provided on shoreline assets was limited to “Vegetative Cover; Wetlands and Floodplains,” so in the discussions it was expanded to include other potentially relevant asset types applicable to the Alameda County shoreline, as shown in Table 2.4. The data types and potential sources identified corresponding to these asset types can be reviewed in Table A2.4 in Appendix A.

Table 2.2 Transportation Stressors / Asset Information

Information Suggested by FHWA to Be Collected to Help Evaluate How Resilient the Asset Is to Climate Change	Stressor Information Further Defined by Transportation Asset Subcommittee and Consultant Team
Age of asset	Age of asset
Geographic location	Geographic location/coordinates
Elevation	Elevation/elevated structure
Current/historical performance or condition (Areas that flood currently require maintenance due to weather impacts)	Current/historical performance or condition (Areas that flood currently require maintenance due to weather impacts)
Level of use (traffic counts, forecasted demand)	Level of use (passenger/ridership, traffic counts, forecast demand, average daily traffic annual average daily traffic)
Replacement cost	Replacement cost
Repair/maintenance schedule and costs	Repair/maintenance schedule and costs
Structural design	Structural design
Materials used	Materials used/material type
Design lifetime and stage of life	Lifetime and stage of life/remaining service life
LIDAR (Light Detection and Ranging) remote sensing data	
Federal Emergency Management maps	
	Susceptibility to seismic hazard/retrofitted

Table 2.3 Transportation Asset Importance - Evaluation and Prioritization Criteria

Criteria
Traffic flow (annual average daily traffic volume, transit ridership, bicycle or pedestrian use)
Interregional travel, such as components of the Interregional Road System
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 (e.g., goods movement, disruption of economic activity, commutes, delay)
Other criteria (e.g., Strategic Highway Network, Surface Transportation Assistance Act routes, Intermodal Corridors of Economic Significance)

Table 2.4 Potential Shoreline Protection Asset Types and Data Sources

FHWA-Suggested Example Asset Categories	Shoreline Asset Types Considered for the Selected Subregion
Vegetative cover, wetlands, floodplains	Nonstructural shoreline protection/baylands /wetlands/ vegetative cover/salt ponds
	Levee (coastal and riverine)
	Seawalls/revetments and nonlevee-engineered structures
	Berm
	Natural nonvegetated shorelines/beaches/cliffs
	Bayshore pump stations

During a Shoreline Asset Subcommittee meeting, representatives discussed the availability, quality, and format of data and how the data could be used for project analysis. During the meeting, it became apparent that additional modeling and updated mapping to show the depth to which transportation and shoreline assets would be inundated would be necessary to fully assess the vulnerability and risk rating of transportation and shoreline protection assets in the subregion. This is an additional step that is not part of the FHWA conceptual model. The methodology for developing the inundation maps is discussed in more detail in Chapter 4.

2.2.3 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 in Appendix A. Where appropriate maps of the GIS data were created, see Figure 2.2 for an example. Lessons learned regarding the data collection exercise are summarized in Section 2.5 of this chapter.

2.2.4 IDENTIFICATION OF ASSET CATEGORIES AND ASSET TYPES

After the initial data collection effort, the project team identified four major asset categories of transportation assets:

a) Road Network
b) Transit Network
c) Transportation Facilities
d) Bicycle and Pedestrian Networks

The project team organized asset types under each of the four categories (Table 2.5) and identified the data required for each asset to facilitate further selection efforts.

2.3 Transportation Asset Selection Methodology

The FHWA conceptual model suggests selecting assets based on their importance to the region (see Table 2.3) (e.g., traffic flow, emergency management, movement of goods), using detailed information from the data inventory. However, after drafting and reviewing a preliminary framework to assess importance as per the FHWA model, the project team decided to change course due to the following factors:

- Most assets in the subregion are arguably important, and the subregion is relatively small (county size), so the team considered the number of assets per asset type to be compared to one another to be too small.
- The amount of data necessary to do a robust importance rating of each asset was beyond the budget and schedule of the project because detailed information was not readily available on individual assets in a readily usable format; also insufficient background information precluded making quantitative assessments/decisions on importance.
- The team did not want to pass over assets that may not meet the importance criteria but that may have intrinsic value for the region (e.g., the Bay Trail).

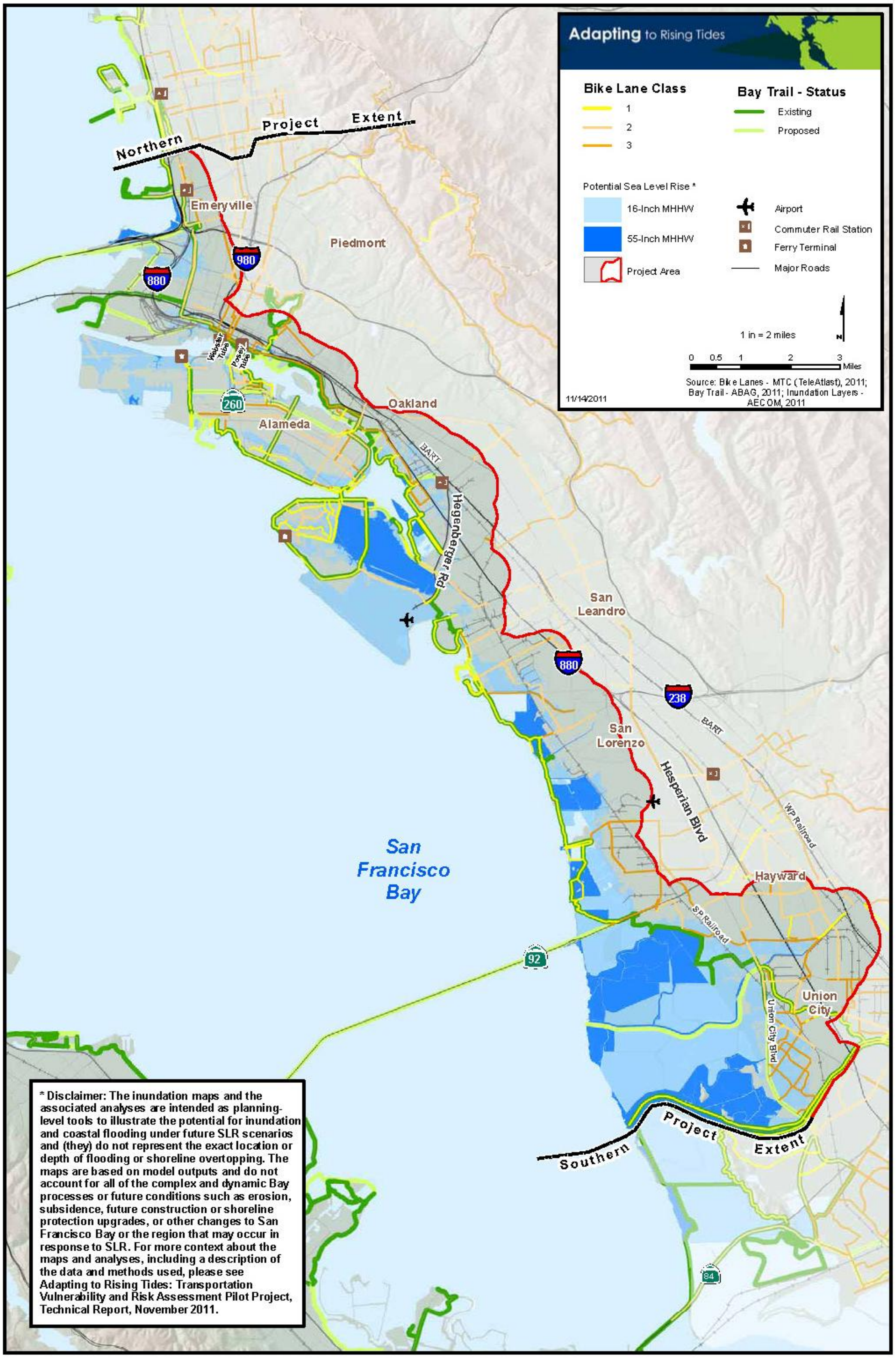

Figure 2.2 GIS Data Available - Example for Bike Lanes and the Bay Trail

Table 2.5 Asset Type Definitions

Road Network	
Asset Type	**Definition (Physical Characteristics, Examples)**
Interstates/ Freeways and State Routes	A freeway is a divided highway that features at least two lanes in each direction operating without signals, stop signs, or at-grade intersections. All interstates are freeways. Example: *Interstate 880.* Some freeways are state routes, but not interstates, such as *State Route 92*. Not all state routes are freeways. In an urban context such as the project area, nonfreeway state routes typically function as "arterials" (see below), such as *State Route 61* (bearing the name *Doolittle Drive*, among others).
Arterial, Collector, and Local Streets	Elements of the roadway network that are not interstates or state routes are identified as "arterials," "collectors," and "local streets" with the support of Google Maps. Streets colored yellow in Google Maps are considered "arterials" and "collectors"; streets colored white are "local streets." Professional judgment is used to differentiate "arterials" from "collectors." Generally, "arterials" have interchanges with the freeway system, while "collectors" do not; "arterials" connect between cities or form major corridors within cities, while "collectors" connect between these major corridors. Examples: arterial – *West Grand Avenue*; collector – *Mandela Parkway*; local street – *Third Street*.
Connectors to Isolated Neighborhoods	Connectors to isolated neighborhoods are identified as a type of unique asset in addition to other "arterial, collector and local streets," which provide the only means of vehicular access to a particular neighborhood or area. Examples: *Powell Street*, *Embarcadero.*
Tunnels and Tubes	"Tunnels and tubes" refers to the *Webster* and *Posey Tubes*, a pair of road tunnels that pass beneath the Oakland Estuary, connecting vehicles, bicycles, and pedestrians between Oakland and Alameda.
Toll, Interstate, and State Bridges	"Toll, interstate, and state bridges" refers to the two bridge crossings of San Francisco Bay, allowing vehicles to cross the bay between Alameda County and San Francisco or San Mateo County. Example: *San Francisco-Oakland Bay Bridge* and *San Mateo Bridge.*
Local Bridges	Local (Alameda) Bridges are a unique type of asset providing a bridge crossing of the Oakland Estuary for vehicles and pedestrians. Example: *Park Street Bridge.*
Transit Network	
Asset Type	**Definition (Physical characteristics, examples)**
Bus Routes	Bus routes are the path of operation of regularly scheduled transit service provided by buses, differentiated by other routes by a specific route number or letter. Bus stops along a bus route are typically marked with signs and may include benches, shelters, and information displays. For purposes of this project, these are not considered as separate assets, but as characteristics of the roadways they are operated on. The project includes as "bus routes" the services of AC Transit, Union City Transit, Emery Go-Round, Amtrak Thruway Buses, AirBART as well as the California Department of Transportation (Caltrans) Bay Bridge Bicycle Shuttle and the Estuary Crossing Shuttle.
BART Lines	BART (Bay Area Rapid Transit) lines are a specialized grade-separated passenger railroad facilitating the exclusive operation of BART trains. The tracks, or guideways, of BART may be supported on aerial structures, be built at grade, or operate in underground tunnels. Examples: *Oakland Wye tunnel* or *West Oakland aerial structure.*
BART Stations	BART stations are facilities designed to receive BART trains, outfitted with (a) platform(s) for passenger boarding and alighting. They are typically elevated or underground. BART guideways are grade-separated; thus stations include circulation areas and elements such as stairways, escalators, and elevators. They may include parking lots, bus transfer facilities, and bicycle lockers, which are not considered separate assets but included as part of the BART station for purposes of this project. Examples: *Lake Merritt Station* and *West Oakland Station.*
Railroads	Railroads support the conveyance of passenger or freight on wheeled vehicles running on rail tracks. In the project area, railroads are used by both passenger (Amtrak) and freight trains. Example: *Union Pacific Coast Subdivision.*
Rail Stations	Rail stations are facilities designed to receive passenger trains, outfitted with (a) platform(s) for passenger boarding and alighting. They may include ticketing, waiting areas, and other amenities. Examples: Amtrak's *Emeryville* and *Oakland-Jack London Square* Stations.

Ferry Terminals	Ferry terminals are facilities designed to receive ferries and allow for passenger boarding and alighting. They may include ticketing, waiting areas and other amenities. Examples: *Jack London Square* and *Alameda Gateway* ferry terminals, serving ferries to San Francisco.
Transportation Facilities	
Asset Type	**Definition (Physical characteristics, examples)**
Traffic / Transportation Management Centers	Traffic or transportation management centers are operated by cities, counties, transit providers, and regional agencies to manage and coordinate traffic and emergency operations and communications. Example: *City of Alameda Traffic Management Center.*
Caltrans Maintenance Facilities	Caltrans maintenance facilities include maintenance yards, weigh stations, fueling and power stations, and other facilities that support the operations of Caltrans roadways (interstate highways and state routes). Examples: the *Webster/Posey Tube Facilities* and the *Interstate 80* and *State Route 92 Toll Plazas*; these are not considered separate assets but as components of the respective roadways.
Bus Service Facilities	Bus service facilities provide storage, operations and maintenance and control facilities for bus service providers. Example: AC Transit is the primary bus-based transit provider in the project area and maintains one of a number of maintenance facilities at *1100 Seminary Avenue* in Oakland.
BART System Assets	Aside from BART guideways and stations, BART system assets include facilities providing storage, operations and maintenance and control facilities for BART operations. Example: *BART O&M Shop* at the south tunnel portal of the Oakland Wye in Oakland.
Rail Yards and Depots	Rail yards and depots provide storage, operations and maintenance (O&M) and control facilities for freight and/or passenger rail operations. Example: *Capitol Corridor Northern California O&M Yard* in Oakland.
Ferry Maintenance Facilities	Ferry maintenance facilities provide storage, operations and maintenance, and control facilities for ferry operations. Example: the Bay Area Water Emergency and Transportation Authority has a planned ferry maintenance facility in Alameda.
Bicycle and Pedestrian Networks	
Asset Type	**Definition (Physical characteristics, examples)**
Trails / Class I Bike Facilities	Trails are off-street, paved, or gravel paths for pedestrian and/or bicycle use. Class I bicycle facilities are separated from motorized vehicular traffic by open space or a barrier (in which case they may be located along a street). Examples: components of the *San Francisco Bay Trail* along the Alameda County shoreline.
Class II Bike Facilities	Class II bicycle facilities are separate bicycle lanes adjacent to the curb lane on a roadway. For purposes of this project, these are not considered as separate assets, but as characteristics of the roadways they are a part of. Example: bike lanes on *Mandela Parkway.*

Thus, the project team amended the process to select representative assets for each asset type and refine the number of assets for which additional data would be requested. Considerations developed for the initial framework, including environmental, economic, and equity considerations that are also used in the larger Adapting to Rising Tides project, were included to develop characteristics and functionalities for the assets (discussed in Section 2.3.1 below). This aided in the selection of representative assets in the project area.

For most asset types, the high number of assets prevented a comprehensive analysis within the scope of this study. Instead, the project team decided to use two filters to narrow down the assets within each type to a short list of representative assets. The first filter limited the assets to only those that would be touched by sea level rise (SLR), as identified using preliminary inundation mapping. Only the portions or segments of these facilities that are projected to be inundated are considered as "assets." The second filter further limited the number of assets using physical functional and socioeconomic characteristics.

Generally, assets with greater functionality or representing a broader range of characteristics were carried forward. In most cases, this resulted in the desired reduction to three or fewer assets per asset type (see Section 2.3.1 below for full explanation of both filters).

In the case of the "Arterial, Collector, and Local Streets" asset type, hundreds of discrete assets can be identified, requiring a more focused approach. The PMT and Transportation Asset Subcommittee participated in an exercise at a Transportation Asset Subcommittee workshop (see Section 2.3.1 below) to identify a particular focus area within which to select representative assets for this type. Participants affixed stickers to maps of the project area showing areas of inundation to "vote" for the areas they deemed would best serve as the focus area. West Oakland and the Oakland waterfront emerged as the focus areas, and representative collectors and local streets were selected from these areas only.

The PMT and stakeholders felt it was important to include transportation facilities from all asset categories and types. Additionally, it was determined that some asset types include within them unique assets, which would be identified in addition to the broader number of assets in that asset type. For example, "Connectors to isolated neighborhoods" were identified in addition to other "Arterial, Collector, and Local Streets" to ensure that assets that might provide the only means of access to a particular area are included. Similarly, "Local Bridges" were identified in addition to other bridges because of their importance to the island City of Alameda. Even for these unique asset types, two to three representative assets were selected, applying the filters described above.

2.3.1 FUNCTIONALITY AND OTHER CHARACTERISTICS TO SELECT REPRESENTATIVE ASSETS

A critical question for the project was whether a transportation asset was "in" or "out" of the potential exposure (inundation) zone for the anticipated end-of-century SLR scenario (see Chapter 4). The transportation assets that were not exposed to SLR were not included in the inventory. (Note that early on in the project, the team did not have the improved inundation maps developed for the project [mentioned earlier; see Chapter 4 for full details] and therefore used the USGS (Knowles 2009) extent of inundation maps and added a half-mile buffer zone to be applied as a first filter.) This resulted in a first shortlist of assets per asset type likely to be inundated. Later in the process, this preliminary list was verified with new inundation maps.

In addition to considering exposure to SLR, additional characteristics outlined below in Table 2.6, were used to narrow down the number of assets further for each asset type. Generally, assets exhibiting more functionalities or with a greater number of quantified characteristics were retained, filtering out assets serving fewer functions or having lesser importance. It should be noted that all assets that are within the SLR exposure zone but were not further assessed as part of the project should be evaluated for vulnerability using the process described in this report by the appropriate agency in the future.

TRANSPORTATION ASSET SUBCOMMITTEE ASSET CATEGORIZATION AND SELECTION WORKSHOP

After the transportation asset categories and types had been established and representative assets selected, a stakeholder workgroup meeting was held for all the transportation stakeholders to comment on the process and provide input on the selection of representative assets. During the meeting, stakeholders received an update on the project, and the preliminary transportation asset categories and types were presented. Printed maps were available showing all the assets per asset type in the SLR exposure zone. The committee was asked to review the asset categories and shortlisted representative assets based on the identified characteristics. This allowed the stakeholders to raise any "red flags" concerning the selection of certain assets.

Table 2.6 Functionalities and Characteristics of Transportation Assets

Characteristic or Functionality	Description
Physical Characteristics	Indicates whether an asset is built at-grade, below grade, or elevated on embankments or structures, through inspection of Google Maps satellite images. For bridges, the structural type was identified as an additional physical characteristic and determined by referencing pertinent Websites. This was intended to ensure that the selected assets reflect a complete range of physical characteristics.
Functionality	
Lifeline Route	Denotes whether or not an asset is included in the Caltrans network of “Lifeline Highway Routes,” as shown on a map prepared by Caltrans District 4’s Office of System and Regional Planning. This applies only to the interstate highways and state routes of “Road Network” assets.
Evacuation Route	Denotes whether or not an asset is designated as an “Evacuation Route” by the cities. This applies only to “Road Network” assets.
Goods Movement	Denotes whether an asset is identified as part of the “Truck Network” in Caltrans GIS data, is a roadway within Port of Oakland property (both seaport and international airport), or provides a direct connection between the Truck Network and Port of Oakland property, by inspection of Google Maps. This applies only to “Road Network” assets and the railroads included in “Transit” assets.
Transit Route	The local bus routes operating on a particular asset (“Road Network” assets) or serving a particular BART or Amtrak station (“Transit” assets) are identified, as determined by inspection of current AC Transit, Emery-Go-Round, and Union City Transit system maps.
Bike Route	Denotes whether an asset is identified as having bike lanes in Metropolitan Transportation Commission (MTC) GIS data (2011), or is included in Figure H.4, “Existing Bikeways,” of the City of Oakland Bicycle Master Plan (2007), or is indicated as an on-street portion of the San Francisco Bay Trail, as indicated on the East Bay map of the San Francisco Bay Trail (2011). This applies only to “Road Network” assets.
Number of Routes	The number of routes serving a bus transit center or ferry terminal, or lines serving a BART segment, is noted, based on inspection of current bus, ferry, and BART schedules and maps. This applies only to “Transit” assets.
Route Type	The bus service route type is indicated, as set forth in the AC Transit District Board of Directors GM Memo No. 11-055, March 9, 2011. This applies only to AC Transit routes of the “Transit” assets.
Ridership	Expressed as daily entries/exits, for BART stations only, as calculated from BART Station Entry/Exit Data (October 2010).
Passenger/Freight function	For railroads only, it is indicated whether passenger service, freight service, or both are served.
Average Daily Passengers	For AC Transit routes, as indicated in the AC Transit District Board of Directors GM Memo No. 11-055 (2011), and for BART line segments, as calculated from BART Entry/Exit Data (October 2010).
Line load	For BART stations only, as calculated from BART Entry/Exit Data (October 2010).
Jurisdiction	Indicates the agency, city, or other entity with ownership and/or management responsibility for the asset.
Social/Economic Considerations	
Commuter Route	Using professional judgment, freeways, Transbay bridges, and the Alameda tubes in the “Road Network” assets are selected and noted as primary commuter routes connecting to jobs. Using professional judgment, BART lines and stations in the “Transit” assets are selected and noted as the primary transit assets connecting to jobs. For “Bike/Ped” assets, it is noted whether a facility provides direct access to a transit asset, as indicated by PMT input.
Regional Importance	Using professional judgment, freeways, Transbay bridges, and roadways connecting the freeway system to Oakland International Airport were selected and noted as assets with regional importance. This applies only to “Road Network” assets.

Characteristic or Functionality	Description
Supports Transit-dependent Populations	MTC data on household car ownership by Census Block (2011) was divided into quintiles. It is noted whether an asset is located in a Census Block in the lower three quintiles, corresponding to Census blocks where 81 percent or fewer of the households own cars. Applies to "Transit" and "Bike/Ped" assets only.
Multimodal	By inspection of current bus, ferry, BART, and Amtrak schedules and maps, it is noted if an asset supports transfers between these modes; for "Transit" assets only.
Maintenance	For "Facilities" assets, it is noted whether a facility supports the maintenance of other transportation assets.
Management	For "Facilities" assets, it is noted whether a facility supports the management of other transportation assets
Recreational Use	For "Bike/Ped" assets, it is noted whether a facility supports recreational use; using professional judgment, all components of the Bay Trail are considered recreational assets

Questions for the Transportation Asset Subcommittee included the following**:**

- Did we pick the "right" criteria/characteristics to determine representative assets?
- Reviewing the asset list, are we missing any characteristics that you would use to determine representativeness of the asset type?
- Which assets do you think are the most representative based on your professional judgment? Would they be determinable with the characteristics chosen?

There was general consensus among the stakeholders on the developed approach and the asset categories and types. Most comments received during and after the meeting applied to characteristics of the assets and information that is available to support the analysis.

The long list of representative assets is shown in Table A2.7 in Appendix A.

SHORT LIST OF REPRESENTATIVE ASSETS AND STRESSOR INFORMATION

The list of selected representative assets was still considered too long for taking forward to the vulnerability assessment stage (see Chapter 5) due to the amount of stressor information that still needed to be collected for that stage and due to budget and schedule considerations. Therefore, decisions needed to be made to further reduce the number of assets.

"CRITICAL, UNIQUE" ASSETS

For a number of asset types, all assets were moved forward to the vulnerability assessment on the basis of their unique nature/criticality as transportation assets for the Bay Area and Alameda County (e.g., all tunnels/tubes). This was particularly applicable where an asset type had only one or two examples. Using the revised inundation data plus functionality characteristics (e.g., whether the asset is a commuter route, goods movement route, transit route, Lifeline Route) already collected, these critical and unique assets were selected from the following asset types:

- Interstates/freeways,
- Arterial streets,
- Road tunnels/tubes (including associated facilities),
- Bay bridges (including toll plazas),
- Alameda bridges,
- BART stations (including associated bus and parking facilities),

- BART alignments,
- Amtrak stations (including associated bus and parking facilities),
- Passenger/freight rail alignments,
- Ferry terminals,
- Transportation management centers,
- Bus maintenance facilities,
- BART system assets, and
- Passenger and freight yards and depots.

The number of arterial assets was reduced to include only those that connect the port or airport to the larger network and/or contain bus routes (e.g., selected based on functionality). One representative Alameda bridge and one representative ferry terminal were selected based on exposure, sensitivity, and level of use. During this phase of asset selection, in order to help rationalize the number of assets, the following decisions also were made:

- A bus route, in contrast to the road that it operates on, was considered a service and not a physical facility that can be protected. Therefore, it was noted which parts of the road network (from freeway to neighborhood street) facilitate a bus route.

- Certain facilities were grouped with the adjoining assets they supported. For example, the BART O&M Shop (near the eastern approach of the Oakland Wye) was considered with Oakland Wye East Portal as a single asset; the Interstate 80 (I-80) Toll Plaza was considered with the landside I-80 segment as a single asset.

- Bus facilities were considered as part of the respective rail station.

- Webster/Posey Tube Facilities (415 Harrison), approaches, and the tubes themselves were considered as a single asset

REPRESENTATIVE ASSET TYPES

The project team used the information collected on inundation and functionality again to further refine the list of “representative” assets/asset segments to undergo a vulnerability assessment for the following asset types:

- Collector streets,
- Neighborhood streets,
- Connectors to isolated neighborhoods, and
- Trails/Class I bicycle facilities.

For example, neighborhood streets were selected if they had additional functionality, such as having transit routes and/or a bike lane. Parts of the Bay Trail were selected that were commuter routes and were in low-car ownership areas. Class II bike facilities were considered as part of the streets they operate on.

SHORT LIST OF ASSETS FOR VULNERABILITY ASSESSMENT

The list of selected assets moved forward for the Vulnerability Assessment is shown in Table A2.8 in Appendix A. This short list of assets was sent to the following relevant agencies—Metropolitan Transportation Commission (MTC), BART, Water Emergency Transportation Authority, California Department of Transportation (Caltrans), Bay Trail, City of Alameda, AC Transit and Capitol Corridor—to collect the final detailed stressor information outlined below that would contribute toward assessing the sensitivity of the asset to inundation by SLR.

DETAILED STRESSOR OR "SENSITIVITY" TRANSPORTATION DATA COLLECTION

The project team met to discuss what the most appropriate stressor criteria should be given the difficulty of accessing data and the availability of data. The stressor criteria provide information on the potential sensitivity of the asset to inundation to SLR. As a result, seven criteria were developed and data was requested from the responsible agencies for selected assets to support the vulnerability assessment (Table 2.7).

Table 2.7 Stressor or "Sensitivity" Criteria

Criterion	Definition
Age of Facility	Defined or recorded in terms of the year the facility was built or the number of years the facility has been in service.
Level of Use	Quantifying traffic volumes for cars and trucks, which may be defined or recorded average daily traffic volumes, annual average daily traffic volumes, annual average weekday daily traffic volumes, peak-hour volumes, peak-period volumes, and/or the percent of trucks that use the facility during a given period. For transit assets, level of use may be expressed in terms of various ridership metrics.
Seismic Retrofitting	Indicating whether structures have been strengthened in order to improve resistance to seismic activity, ground motion or soil failure due to earthquakes. Seismic retrofitting is usually required for structures built prior to 1975, as seismic codes were not as rigorous at that time. For the roadways, seismic retrofitting would typically be expected on bridges or similar structures along the specified segments. Seismic retrofitting of bridges involves strengthening columns with steel casing and in some cases may also involve the strengthening of footings, abutments, and hinges.
Operations and Maintenance (O&M) Costs	Recorded in terms of annual O&M costs for each facility, estimated lifetime O&M cost, and/or annual O&M cost per lane. Maintenance includes activities to keep pavement, shoulders, slopes, and drainage facilities functioning properly, which may include grading, resurfacing, crack sealing, patching potholes, asphalt concrete overlaying, and spot rehabilitation. Maintenance does not include building shoulders or widening roads.
Condition	Depending on the asset type, other methodologies or rating schemes, which may be proprietary, may be in place to assess the "condition" of particular assets with respect to other assets.
Liquefaction Susceptibility	Provided by ABAG (2011). The liquefaction susceptibilities of points within the subregion are assigned a ranking of "very low," "low," "moderate," "high," or "very high."
Foundation Condition	Foundations or subgrades supporting roadway segments and any structures, such as bridges, along the segments. Data may include the type of foundation, the age of the foundation, the extent of the last maintenance in regards to the foundation and any existing foundation issues. Foundations may be shallow or deep, isolated or combined and with and without piles. Foundation issues may include movement, settlement, and cracking.

Within the schedule required for the project, information was generally available only for the road network. Data exist for the transit facilities but were not easily accessible in the timeframe required. The information collected is summarized on the risk profiles of the most vulnerable assets; see Section 5.4, Chapter 5.

2.4 Shoreline Asset Categorization

The shoreline assets were categorized using a method different from that used for transportation assets. The shoreline categorization focused on identifying the main line of shoreline defense (and protection assets) along the subregional coastline because the primary focus of the FHWA conceptual model is to understand the risk and vulnerability of transportation assets. However, the vulnerability of shoreline assets clearly plays an important role in the vulnerability of transportation assets. For this project, the primary drivers affecting transportation asset vulnerability and risk related to the shoreline assets were as follows:

- Shoreline asset type (or suite of types creating a flood protection system that protects a transportation asset) and elevation,
- Inundation level at the shoreline asset (e.g., the depth of inundation directly over a flood protection levee, not inland of the levee), both under daily tidal inundation (mean higher high water [MHHW] plus SLR) and under 100-year storm events (stillwater levels and stillwater levels plus wind wave effects), and
- Wave climate (wave height, period, and velocity) outboard of the shoreline asset(s).

To conduct this analysis, stretches of shoreline were categorized in a GIS mapping exercise. This allowed the project team to analyze the shoreline near a transportation asset to better understand inundation behind the shoreline asset. The five agreed upon shoreline categories for this project are as follows:

- Engineered Flood Protection Structures
  - Levees
  - Flood Walls
- Engineered Shoreline Protection Structures
  - Bulkheads
  - Revetments
- Nonengineered Berms
- Wetlands
  - Natural
  - Managed
  - Tidal Flats
- Natural Shorelines (Nonwetland)

These shoreline asset categories attempt to collapse a highly varied and diverse shoreline into distinct classes that will support the vulnerability and risk assessment. The categories were defined based on their primary function and are presented in order from those assets that provide the most potential protection from inundation to those assets that have the least potential for inhibiting inland inundation.

The engineered flood protection structures protect inland areas from flooding and inundation; engineered shoreline protection structures harden the shoreline to reduce erosion and prevent land loss; nonengineered berms protect marshes and ponds from wave erosion and provide flood protection to inland developments and, in some cases, serve to maintain hydraulic separation between the bay and the protected/ managed areas; wetlands dissipate wave energy and provide ecological habitat value; and other natural or managed nonwetland shorelines, such as natural or artificially maintained beaches, can provide some wave energy dissipation. Figure 2.3 shows locations of example shoreline asset categories.

Figure 2.3 Location of Shoreline Asset Examples

2.4.1 ENGINEERED FLOOD PROTECTION STRUCTURES

LEVEE

Engineered levees are one of the most common forms of riverine and coastal flood protection. The primary purpose of a coastal levee is to prevent inland flooding from major storm events and extreme water levels that may also be accompanied by large, powerful waves. Figure 2.4 depicts an aerial view of an engineered levee at the Oakland International Airport. The roadway is located along the levee crest. The outboard slope (or embankment) of the levee is armored with a riprap revetment that protects the levee from wave- induced erosion. Figure 2.5 presents a generalized schematic of a coastal levee. Levees are engineered to meet certain design criteria with respect to freeboard (distance between the 100-year stillwater elevation (SWEL) plus wave run-up and the levee crest), embankment protection, embankment and foundation stability, and settlement. Levees are generally designed, at a minimum, to provide protection from the 100-year coastal event (high-water levels and waves).

The protective value of a levee changes as sea level rises. As sea level rises, MHHW and the 100-year SWEL also rise. This could result in a reduction or elimination of the levee freeboard, resulting in an increase potential for levee overtopping and inland inundation of the protected areas behind the levee. The list below presents the progression over time of the level of protection provided by a levee as sea level rises, assuming no levee upgrades occur:

- The 100-year SWEL and the maximum wave run-up associated with that SWEL do not overtop the levee, but the levee no longer meets its original freeboard design criteria.

- The 100-year SWEL is below the levee crest, but the combination of the 100-year SWEL and the maximum wave run-up condition results in levee overtopping; therefore, levee overtopping occurs primarily during extreme events with large waves.
- The 100-year SWEL is above the levee crest, resulting in levee overtopping. The levee would be routinely overtopped during extreme high-water events regardless of the wave conditions.
- MHHW is above the levee crest, resulting in levee overtopping. The levee would be routinely overtopped.

An additional vulnerability factor not considered in the above scenarios is the impact on the existing levee conditions as sea level rises. SLR may be accompanied by larger and more frequent waves, which could result in erosion of the levee embankment. In addition, levee overtopping, whether frequent or infrequent, could result in erosion along the levee crest and the backside of the levee, thus weakening the levee and increasing the potential for levee failure.

Most engineered levees are regularly maintained by the agencies responsible for the levee; therefore, it is likely that the levees would be upgraded in order to accommodate changing conditions and maintain existing levels of flood protection. Levees can be upgraded by increasing the height (and also the overall footprint of the levee). If the levee footprint cannot be expanded due to land use constraints, levees could be upgraded by combining them with other means of flood protection, such as constructing a flood wall along the levee crest.

Figure 2.4 Engineered Levee with Revetment: Oakland International Airport, Oakland; Roadway Is Levee Crest

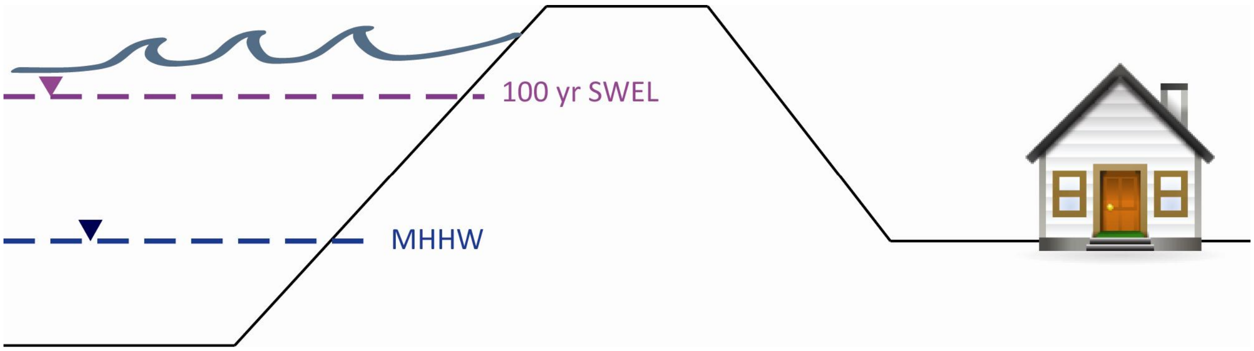

Figure 2.5 Schematic of Levee Cross Section

FLOOD WALL

A flood wall is a vertical barrier designed to protect inland areas from flooding. Figure 2.6 shows the flood wall protecting the Eden Shores neighborhood adjacent to the Eden Landing Complex in Hayward. The design standards for flood walls are similar to those of an engineered levee in that the critical components are the amount of freeboard and overall stability. Flood walls are also vulnerable to SLR in a manner similar to engineered levees.

Figure 2.6 Flood Wall: Eden Shores, Landward of Eden Landing Complex, Hayward (Nonengineered Berm also Pictured to the Right of the Floodwall with Roadway as Berm Crest)

2.4.2 ENGINEERED SHORELINE PROTECTION STRUCTURES

Although engineered levees are one of the most common forms of engineered flood protection, other forms of engineered structures also exist along the San Francisco Bay shoreline. Along the Alameda County shoreline, bulkheads and revetments are the most common engineered shoreline protection structures. Shoreline protection structures differ from flood protection structures because their primary purpose is to harden the shoreline and reduce land erosion and land loss. Shoreline protection structures are not designed to provide protection from inland flooding.

BULKHEAD

A bulkhead is a vertical retaining structure designed to reduce land loss. Its secondary purpose is to protect inland areas from wave damage. Bulkheads can be cantilevered over the water surface or solid structures with earthen backfill behind them. Figure 2.7 depicts a bulkhead in the Port of Oakland Inner Harbor Turning Basin. Bulkheads are not designed to provide flood protection. As sea level rises, the functionality and stability of the bulkheads can be compromised, leading to bulkhead collapse and failure of the bulkhead support structures.

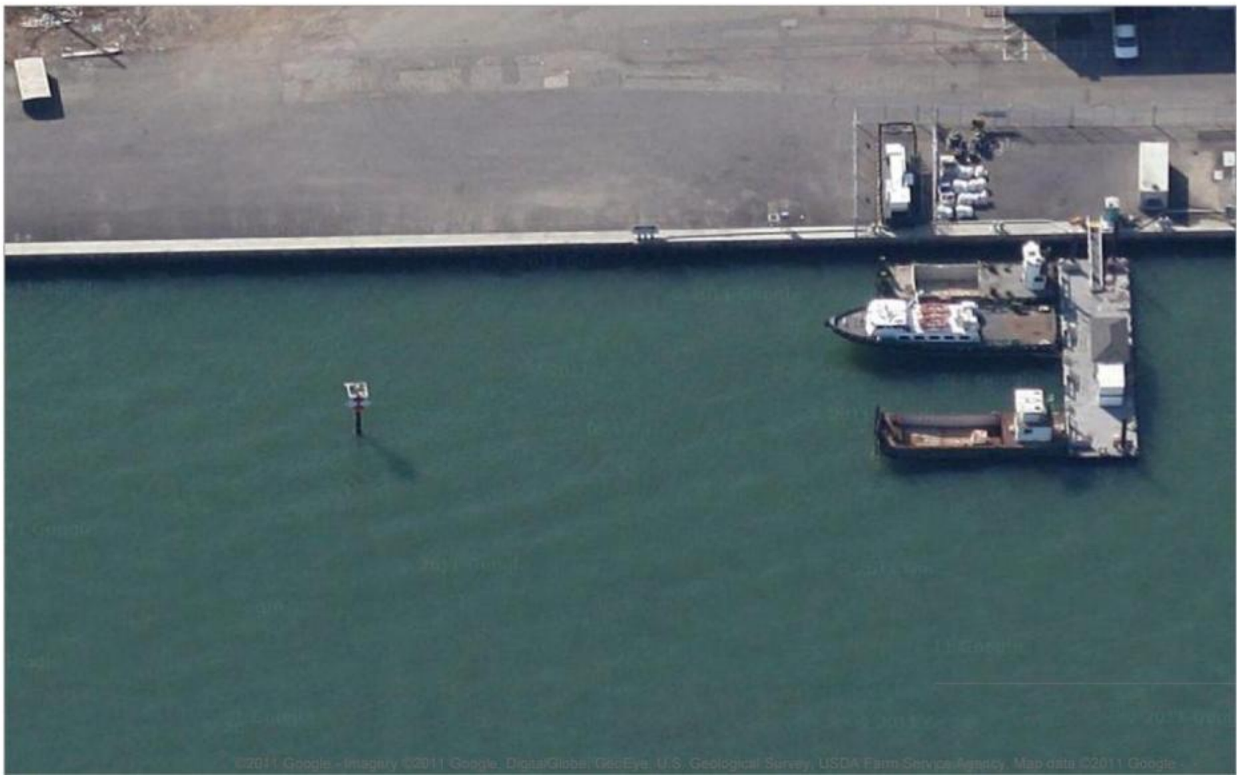

Figure 2.7 Bulkhead, Port of Oakland, Oakland

REVETMENT

Revetments are designed to protect the shoreline from waves and strong currents and to inhibit wave-induced erosion and land loss (CEM 2006). In general, revetments are a cover, or facing, of erosion-resistant material (such as concrete or riprap) placed on an existing slope or an engineered embankment to protect the area from waves. A revetment hardens the shoreline and maintains its position. The three major components of an engineered revetment are a stable armor layer, a filter cloth or underlayer, and toe protection. Along the San Francisco Bay shoreline, revetments are common. Revetments can exist alone, as shown for the Shoreline Park (Figure 2.8), or they can exist in combination with other structures.

For the Port of Oakland, revetments exist alone and/or underneath pier structures (Figure 2.9). Revetments can also exist in combination with other forms of coastal flood protection, such as along engineered levees (Figure 2.4), nonengineered berms (Figure 2.10), and inland of wetlands (Figure 2.11). Along nonengineered berms, most often the visible riprap armoring is not truly a revetment because the structure has not been engineered and it does not contain the three major components noted above. In this case, riprap is often added in an ad hoc manner as erosion is noted. Revetments, by themselves, are not designed to provide flood protection. As sea level rises, the functionality and stability of revetments can be compromised. The primary failure modes as sea level rises are:

- Armor layer damage: the armor layer is designed for existing wave conditions. In the case of a riprap revetment, the riprap size (or rock/stone size) is selected so that it will remain in position under strong currents and wave conditions. As sea level rises, wave heights and velocities may increase, thus conditions could exist where the armor is mobilized.
- Overtopping: overtopping could result in a loss of foundation material.

Figure 2.8 Revetment, Shoreline Park, Alameda

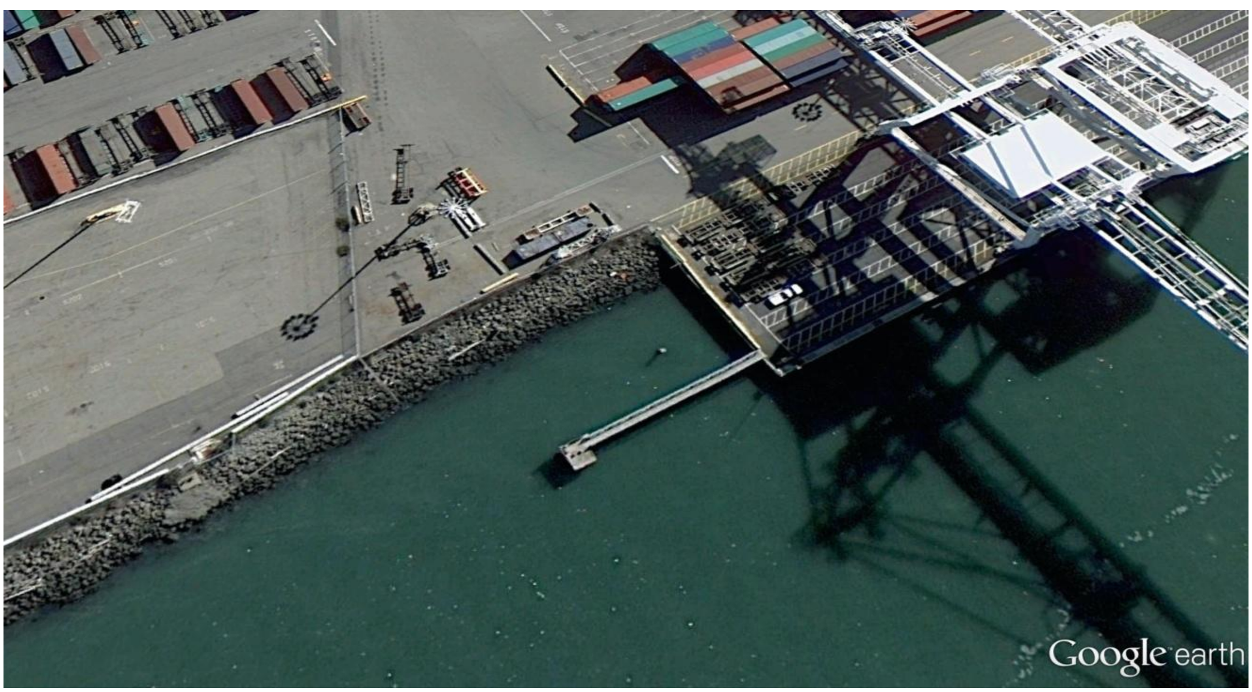

Figure 2.9 Revetment, Port of Oakland, Oakland

Figure 2.10 Nonengineered Berm with Riprap Protection, Hayward; Roadway Berm Is Berm Crest

Figure 2.11 Riprap Protection for Wastewater Treatment Plant, San Leandro (Wetlands and Tidal Flats Outboard)

- Toe failure: the toe protection provides support for the revetment. As the wave and current conditions change and exceed the design conditions, the toe could experience undercutting and the entire revetment could unravel.

- Revetments can be upgraded over time as sea level rises. This may result in placing an additional armor layer with larger rock/stone sizes that are sized for the increasing wave conditions. The height of the revetment along the slope would also need to increase to account for the higher water levels and wave heights, and the toe protection would need to be increased to account for the increased size of the overall structure. If the revetment has reached its maximum size, limited by the height of the slope it is protecting, and additional protection is still required, the revetment may need to be coupled with an engineered flood protection structure.

2.4.3 NONENGINEERED BERM

Nonengineered berms are similar to engineered levees in appearance; however, there is a very notable difference between the two. Nonengineered berms have not been engineered to meet the design criteria for a levee. The most common nonengineered berms around San Francisco Bay are the salt pond berms. These berms are essentially mounds of bay mud that have been excavated from the bay floor and piled and/or stacked in a mound. As the mound settles, grading equipment can be used to shape the structure and create a roadway surface, if desired. Figure 2.12 shows the “Mallard,” a specialty dredging machine that is used to build and maintain the salt pond berms. The characteristics of salt pond berms vary greatly. Some appear more structurally sound, particularly along the bayfront where the berms are often large in order to provide wave protection. Many berms contain maintenance roadways along the crest (Figure 2.13) and riprap protection on the wave-exposed sections (Figure 2.14). The riprap protection found along these berms can consist of concrete construction debris.

Figure 2.12 Maintenance of a Nonengineered Berm in Eden Landing by the Mallard, Hayward

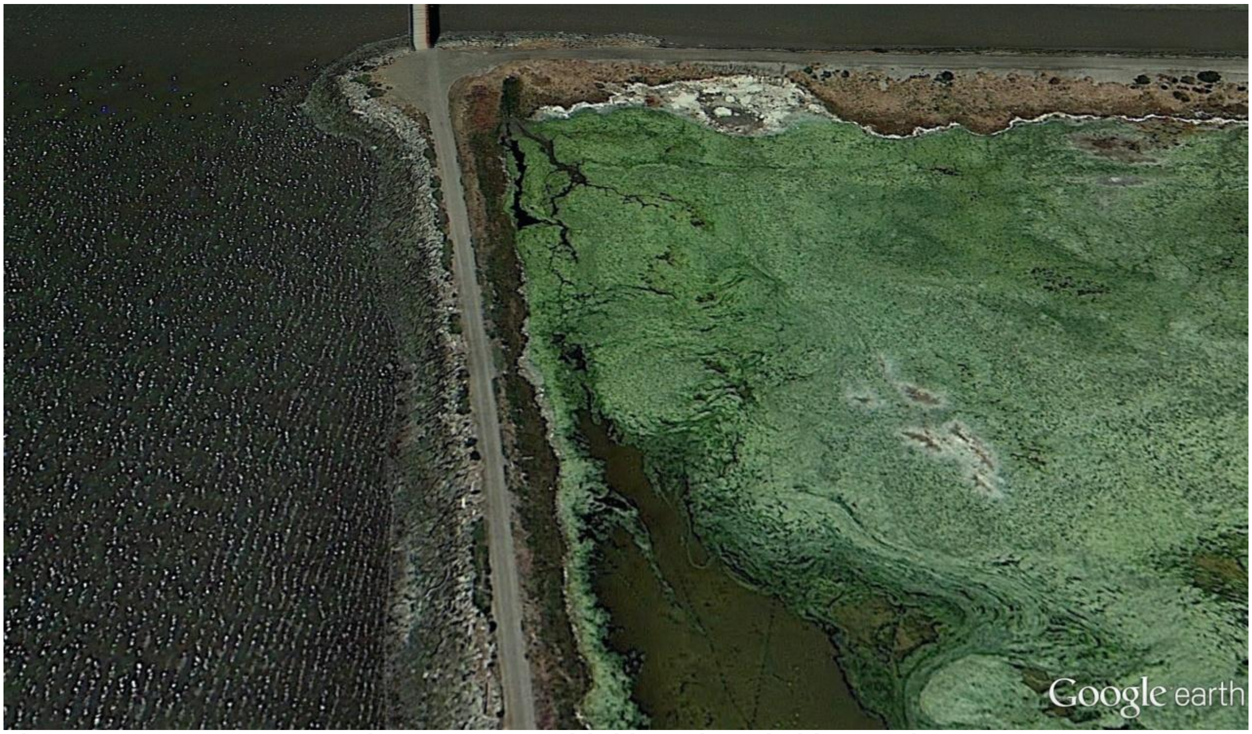

Figure 2.13 Former Salt Pond Berm, Hayward (with Outboard Tidal Flats)

Nonengineered berms are often maintained in a reactive fashion as erosion is observed or as failures occur. Many berms undergo maintenance on a regular cycle based on the level of wave exposure (e.g., outboard berms are maintained more often than inland berms). This type of structure was not designed or intended to provide flood protection to inland areas. However, they do provide some level of ad hoc flood protection to inland developments. Many of the salt pond and former salt pond networks are expansive, thus providing a substantial buffer between bay water levels and waves and inland developed areas.

Nonengineered berms are extremely vulnerable to SLR. The berms can continue to be built up over time. However, current maintenance practices with the Mallard rely on adjacent borrow of bay mud (i.e., the bay floor directly adjacent to the berm is excavated and placed on top of the berm). Many of these adjacent borrow pits are already very deep; therefore, this source of material could be exhausted over time, requiring suitable material to be imported. Due to the nonengineered nature of these structures, there may also be a maximum height limit to which they can be built.

2.4.4 WETLANDS

The value of wetlands for flood protection and wave dissipation purposes is not well understood. Although it may seem intuitive that a large expanse of wetlands would help dissipate waves propagating inland, quantifying this can be difficult. Several different types of wetlands exist along the Alameda County shoreline. Figure 2.15 depicts the Emeryville wetlands to the north of the Oakland-Bay Bridge, directly adjacent to I-80. These wetlands have a natural marsh edge that is fully exposed to the bay. Figure 2.16 depicts a range of wetland habitats at the confluence of the San Lorenzo Creek and the bay. The habitats transition landward from shallow subtidal, to tidal flats, to fringing marsh, to managed marsh on the inland margin. Some of the inland developed areas, in particular the wastewater treatment plant, have a riprap armored shoreline. The Hayward shoreline is a complex mosaic of managed marshes and managed ponds

Figure 2.14 Nonengineered Berm with Riprap-Protecting Tidal Marsh from Wave Erosion, Hayward (see Hayward Marsh Figure 2.17 below under "Wetlands")

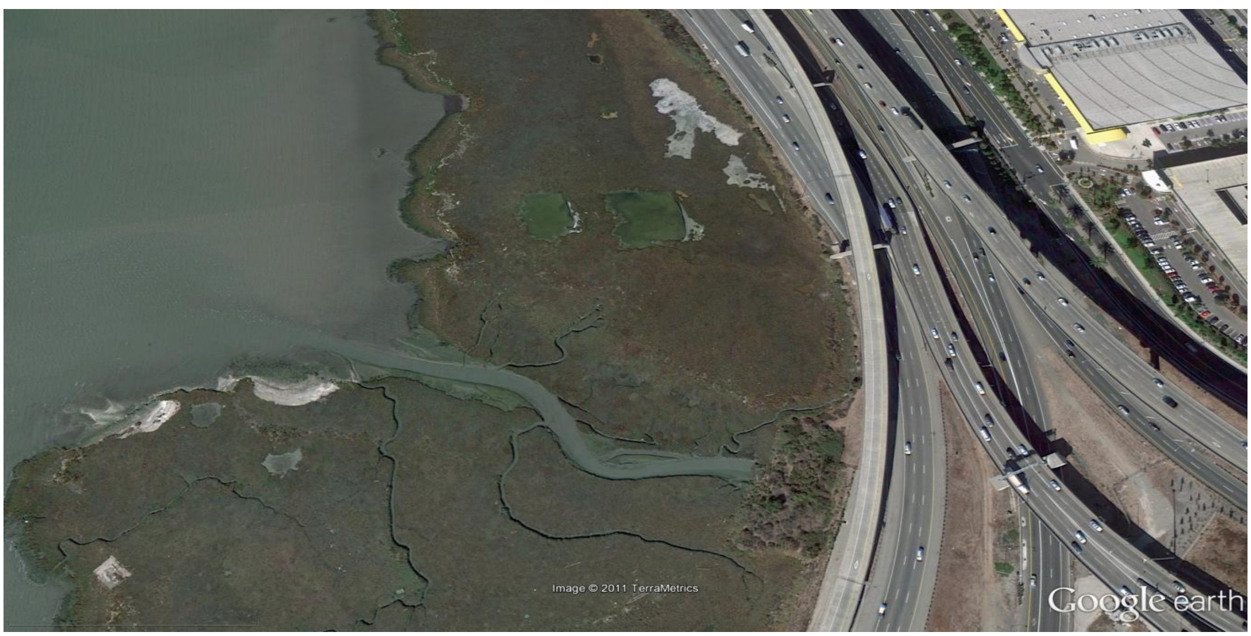

Figure 2.15 Wetlands with Natural Marsh Edge, Emeryville

Figure 2.16 San Lorenzo Creek Tidal Flats, San Leandro (Some Inland Areas Have Riprap-Armored Shoreline; see Figure 2.21)

(Figure 2.17). The outboard regions of the wetlands all contain nonengineered berms to provide wave protection, with the exception of Whales Tail marsh in the Eden Landing Complex just south of the San Mateo Bridge (Figure 2.18).

Historically, wetlands have kept pace with SLR in the bay by accumulating sediment and organic material at a rate similar to SLR. It is not known if wetlands will keep pace with accelerated rates of SLR. For most wetlands, such as the Emeryville wetlands shown in Figure 2.15, there is no inland space for landward migration of the wetland. The wetlands along the Alameda County shoreline will either keep pace with SLR, or they will drown and disappear, unless provision is made for their landward migration. Fringing wetlands directly outboard of developed areas are at greatest risk of disappearing. A recent study by PRBO Conservation Science (PLoS 2011) however indicates that it is unlikely that Bay Area marshes will be able to keep pace with anticipated sea level rise at the end of the century. Changes to wetlands are a focus of the larger ART project.

2.4.5 NATURAL SHORELINE (NONWETLAND)

Natural nonwetland shorelines also exist along the Alameda County shoreline. The most notable stretch of natural shoreline is Robert Crown Memorial State Beach in Alameda (Figure 2.19 and Figure 2.20). The beach is 2.5 miles long, backed by sand dunes. The beach is maintained with imported sand and engineered sand-retaining structures.

Although the beach and the dunes do provide protection to the inland area from large waves, both the beach and the dunes are erosional. As sea levels rise and wave intensity increases, natural shorelines such as these will be extremely vulnerable to SLR. Over time, the sand dunes could require a revetment to harden the shoreline and protect the roadway, and the beach would entirely disappear if it were not maintained with continued sand import. Vegetation can also be added to protect against erosion in the short term.

Figure 2.17 Managed Wetlands, Hayward (Protected Tidal Marsh, Managed Marsh, Managed Ponds – Extensive Nonengineered Berm Networks)

Figure 2.18 Whales Tail Marsh, Eden Landing, Hayward

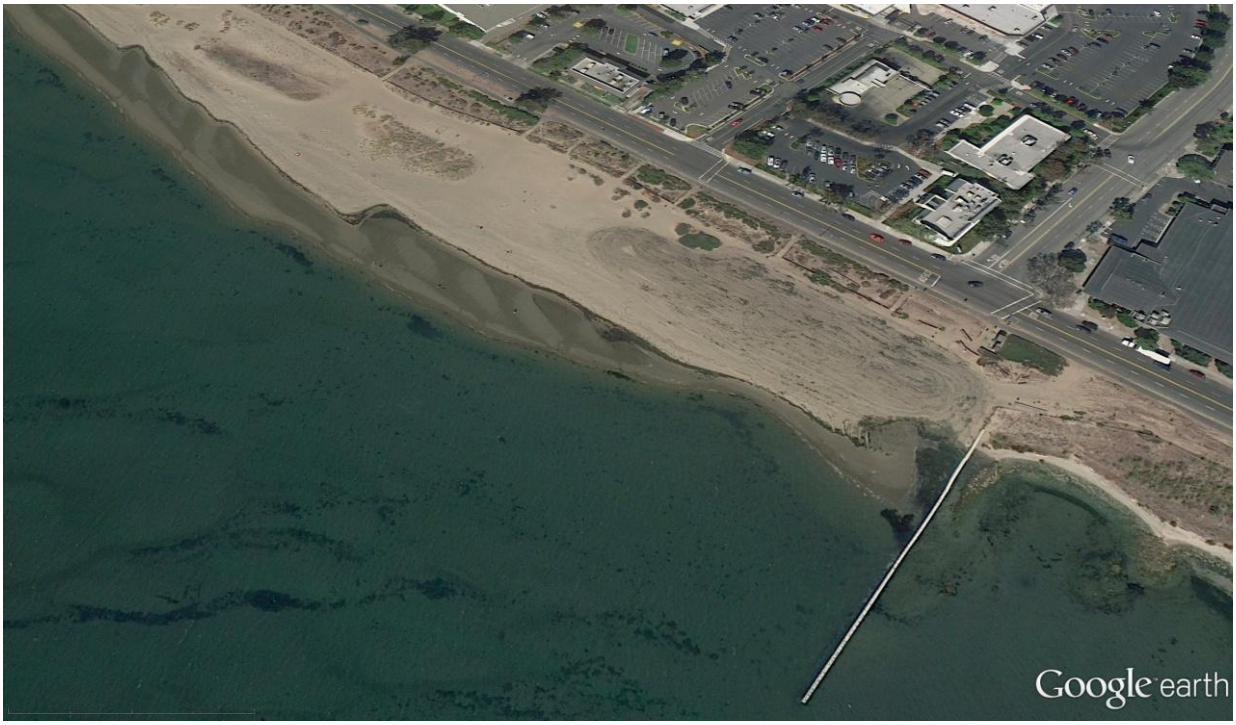

Figure 2.19 Beach – Robert Crown Memorial State Beach, Alameda (Beach Is Erosional and Maintained through Beach Nourishment [i.e., Imported Sand])

Figure 2.20 Beach – Robert Crown Memorial State Beach, Alameda (Steep Sand Dunes Lead to Bicycle Trail and Roadway)

2.4.6 SHORELINE CATEGORIZATION MAPS

This project specifically developed shoreline categorization maps (Figure 2.21and Figure 2.22), using the shoreline categories defined above, because existing data did not meet project needs. Several agencies have "classified" the San Francisco Bay shoreline for different purposes using various classification schemes. The San Francisco Estuary Institute (SFEI) has developed detailed maps that classify habitat types along the shoreline; the National Oceanic and Atmospheric Administration (NOAA) classifies the shoreline using an "environmental sensitivity index" that ranks the sensitivity of various shoreline categories to an oil spill; the Federal Emergency Management Agency (FEMA) has divided the shoreline into distinct reaches for transect-based onshore coastal wave hazard analysis, where each distinct reach has uniform characteristics along its length (e.g., type of protection, slope, land use, wave climate). Although both SFEI's and NOAA's classifications are helpful, neither approach fits the criteria or categorization needs laid out by the project. FEMA's classifications most closely match the project's needs, but the data were not in a readily usable GIS format.

SHORELINE CATEGORIZATION MAP METHODOLOGY

On a county-wide scale, a combination of NOAA data (the ESI index and the NOAA shoreline delineation) and SFEI data (the EcoAtlas and Bay Area Aquatic Resource Inventory data), along with Alameda County's levee alignment file and aerial imagery from Google Earth, was used to classify the shoreline into the five categories listed above. This approach maximized the use of readily available data sets and limited the need for manipulation and conversion of non-GIS to GIS formats. NOAA's environmental sensitivity index data provided a detailed breakdown that could be parsed into the five categories created for this project; however, the data categorize the shoreline based on its most outboard land use and its sensitivity to fouling in the event of an oil spill. The most outboard land use may not adequately capture the most relevant land use for the risk assessment of a transportation asset. For example, NOAA's designated shoreline categories adjacent to the Oakland International Airport are "riprap" and "tidal flats." However, an engineered flood protection levee is landward of the riprap and tidal flats. For this project, the engineered flood protection levee is the most important shoreline asset for the vulnerability and risk assessment. The draft shoreline categorization maps were shared for review with the San Francisco Bay Conservation and Development Commission and Alameda County Flood Control and Water Conservation District, whose comments were included in the final maps.

Figure 2.21 and Figure 2.22 show the different shoreline categories in the pilot area.

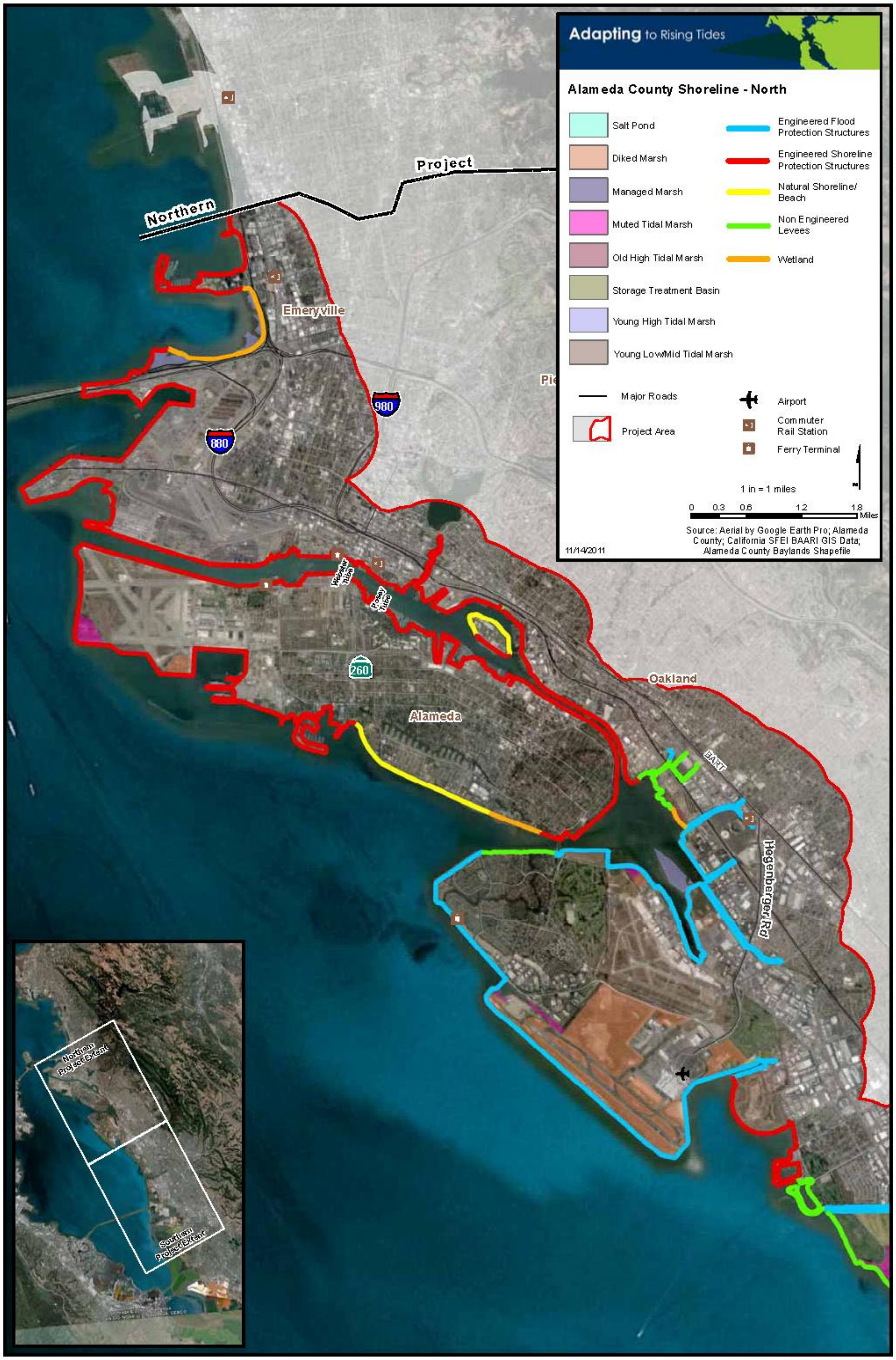

Figure 2.21 Shoreline Categorization Map – Northern Extent

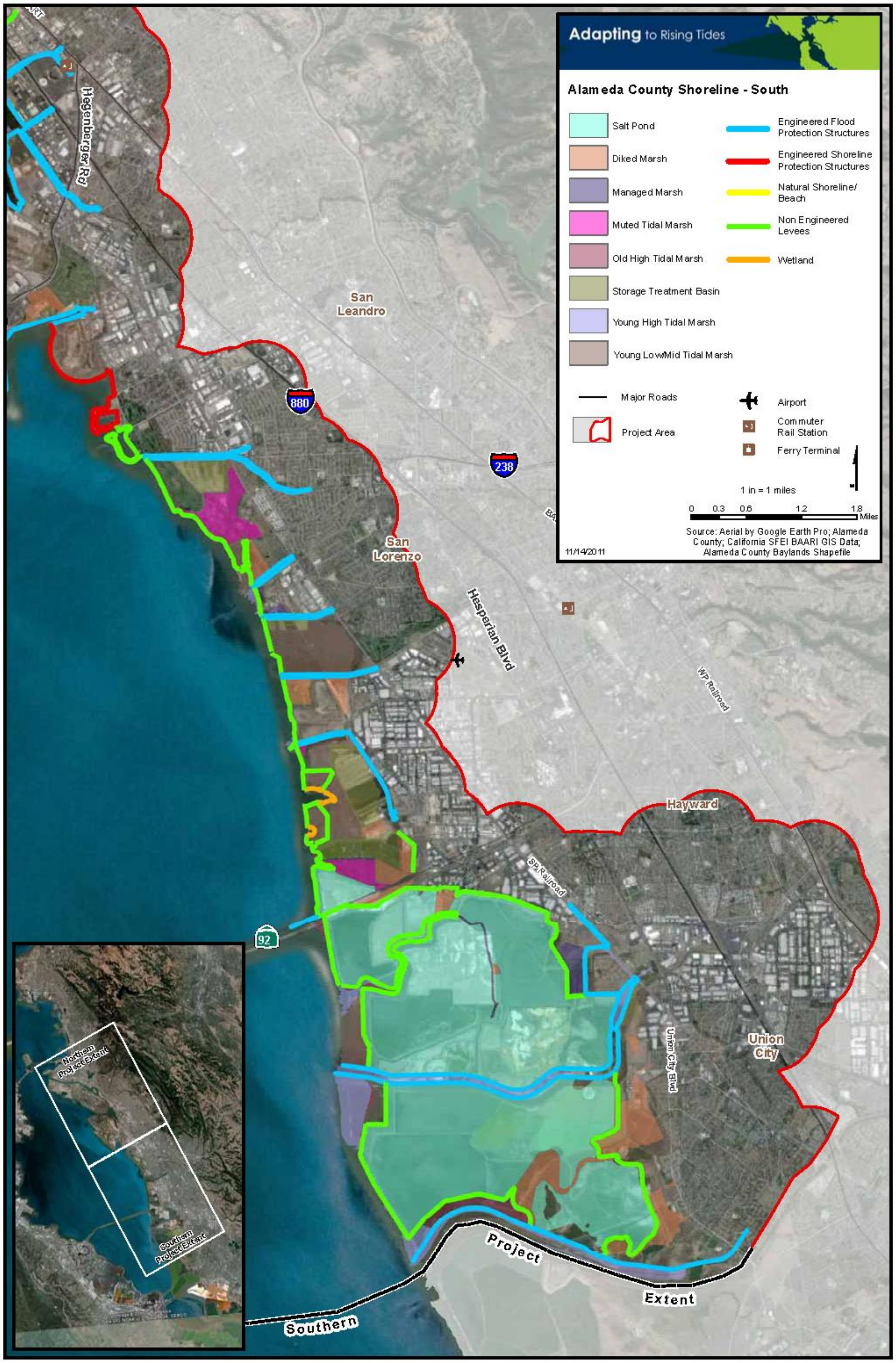

Figure 2.22 Shoreline Categorization Map – Southern Extent

2.5 Recommended Refinements to the FHWA Conceptual Model

This section provides feedback on the FHWA conceptual model and its application in the selected Alameda County subregion in terms of the data collection process and working with local stakeholders.

2.5.1 DATA COLLECTION AND SYNTHESIS ISSUES

Overall, the FHWA conceptual model provided useful guidance for requesting transportation and shoreline asset information. The model also allowed the team to clearly outline the overall process of the vulnerability and risk assessment to stakeholders, the need for data collection, and how the data would be applied.

The process of retrieving and compiling the data from stakeholders was a challenging and lengthy task that took several months longer than initially expected because data were readily retrieved only if specifically requested. Overall data was not readily accessible in useful formats. Even though MTC and Caltrans provided the majority of the transportation data, some were available only from local agencies and stakeholders. It became evident that the collection of more detailed and asset-specific attributes or “stressor” information required paring down the number of transportation assets and selecting a smaller subset of transportation assets in the subregion due to the time consuming nature of the data collection activity. However, the initial collection of regionwide GIS data provided important insights for the subsequent data and asset selection effort.

In addition, the shoreline asset data proved difficult to collect. The project team had assumed that the Alameda County Flood Control and Water Conservation District would provide detailed information on the majority of the shoreline protection assets (e.g., location, elevation, protection type) in GIS format. However, this information was only partially available, which was also the case with information from NOAA and SFEI. A great deal of effort was therefore put into the shoreline categorization, inundation mapping, and overtopping analysis. It would have been helpful for the FHWA conceptual model to mention how important this information is, and to provide guidance on the treatment of shoreline assets in this process, along with different approaches for its inclusion into the asset selection and subsequent steps.

2.5.2 LESSONS LEARNED

The following lessons were learned as part of the pilot project, with a focus on data collection:

- Many datasets are available only in a nonspatial, tabular, or report format, making data extraction and analysis for such a large area very difficult and work-intensive.
- The transportation base data (roadway networks by a third-party provider), despite having a hundred-page user guide, unfortunately were not helpful in determining attribute information.
- Some data sets contained little or no metadata (background information about the data provided).
- To manage the level of effort required to extract the information embedded in reports, data were not requested for all transportation assets initially.
- Data collection was not, therefore, restricted to one phase of the project but continued throughout, as functionality and other characteristics narrowed the asset list to a more manageable length.

- Readily accessible information was critical to the selection of assets for further analysis, in order to facilitate timely project completion.
- One of the biggest difficulties was not necessarily obtaining the data but managing the expectations of the project team regarding what can be done with the data received because many data sets did not provide much detail beyond the location of assets (e.g., very little physical attribute data was readily available in a usable format).

2.5.3 RECOMMENDATIONS FOR FUTURE APPLICATIONS

Recommendations for the data inventory component of the process include the following:

- Creating the data inventory was a helpful first step to understanding the benefits and limitations of the data available. However, a project with numerous assets and a limited budget or timeline will likely require the collection of more detailed data for a refined list of assets during the vulnerability assessment phase. Thus, we recommend splitting up the data collection effort into overall and focused exercises.
- The suggested importance criteria development was not useful for the Alameda County subregion, and an alternative approach assisting in the selection of representative assets may be useful for future projects involving a subregional analysis.
- Determining the criticality of one asset over another was not politically acceptable, given that the assessment would have been largely based on professional judgment and limited data.
- The most important asset selection filter was exposure to flooding and inundation (location of an asset in the projected inundation zone); characteristics and functionality were only marginally involved in reducing the list of assets. (This is consistent with the Guidance on SLR by Caltrans, May 16, 2011.)
- The USGS (Knowles 2009) SLR extent raster data were useful for preliminary mapping and asset selection purposes, especially for prioritizing potentially exposed transportation assets. The team initially used the original extent of inundation maps from USGS for a rough indication of transportation assets at risk of exposure. Without this information available, it would have been more difficult to pinpoint the necessary geographic information, and it helped the stakeholders visualize vulnerable assets.
- Agencies should be advised of the data required to carry out vulnerability to SLR and should start to collate this data going forward in order to facilitate future assessments in database and GIS formats.

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Seismic Vulnerability Assessment 3.0

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3 Seismic Vulnerability Assessment

3.1 Introduction

The project area is in an area of high seismic vulnerability, so all of the transportation assets are at risk from ground shaking and liquefaction of unconsolidated soils. In a sea level rise (SLR) scenario, rising groundwater levels could lead to an increased likelihood of liquefaction and lateral spreading, magnifying the impact of an earthquake. Through a review of the available geographic information system (GIS) information from the California Department of Conservation, U.S. Geological Survey (USGS), and Association of Bay Area Governments (ABAG), this chapter qualitatively analyzes the impact of high seismic vulnerability and how this, coupled with rising seas, might affect the resilience of existing shoreline protection systems and selected transportation assets. As part of the process, the project team met with ABAG and USGS to discuss what issues should be covered and to collect data and GIS resources. Current seismic hazards are reviewed in Section 3.2, and seismic vulnerability from direct inundation and indirect groundwater rise is described in Section 3.3. This process is described in Figure 3.1 below:

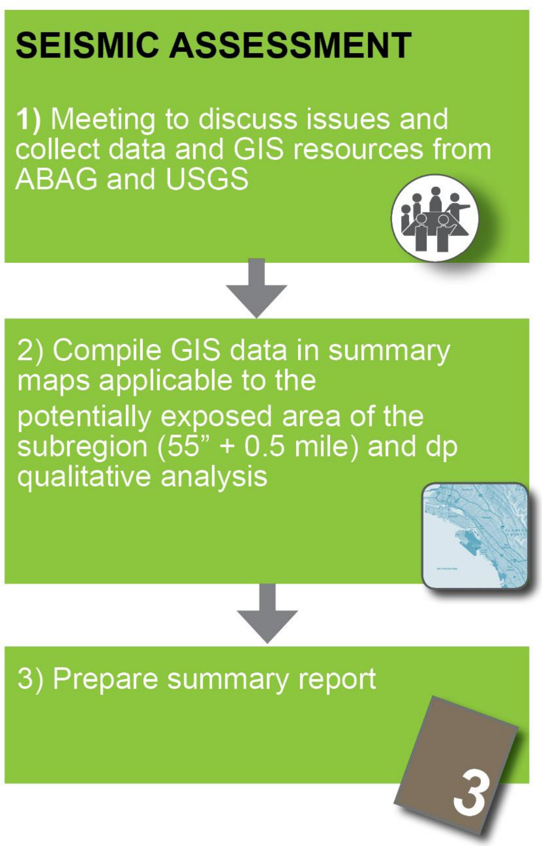

Figure 3.1 Seismic Vulnerability Assessment Process

3.2 Current Geotechnical/Seismic Hazard Conditions

This section qualitatively evaluates the seismic vulnerability of the identified transportation and shoreline assets relative to potential SLR. In order to address seismic vulnerability and assess potential risk to the transportation and shoreline assets, the current primary geotechnical and seismic hazard conditions in the project area are summarized below.

3.2.1 SOFT/WEAK SOILS/FILL

In comparing the historical baylands and modern baylands maps (Figure 3.2 and Figure 3.3), along with other documented San Francisco Bay fill maps (Hitchcock et al. 2008), and overlaying the maximum (55-inch) inundation area, it is evident that a majority of the project area has zones of bay fill that was placed at various times over the past century and a half. Importantly, a majority of this bay filling occurred prior to the 1960s, before much stricter controls and engineering criteria were imposed on subsequent bay filling. Also note that some of the easternmost fringes of the maximum (55-inch) inundation area extend beyond documented fill areas, particularly in the Union City area in southern Alameda County.

Since the mid-1800s, hundreds of millions of cubic yards of fill materials have been placed into San Francisco Bay to reclaim marshland, tidal land, and submerged land. Urbanization was allowed to extend into the bay through the incremental placement of artificial fill on bay mud and natural drainage channel deposits. The predominant native marine deposits beneath the bay fills include the younger bay mud overlying the older bay mud. The history of bay filling is complex from the standpoint of variation in material type and placement methods. A recent report on mapping of artificial fills in the bay indicates that methods of fill placement and types of materials used over the past century directly correlate with the progressive bayward growth of the bay shoreline (Hitchcock et al. 2008). The mapping report indicates that the historical progression of fill evolved from dumping sand from the bay, to hydraulic filling using sand from the bay to modern engineered fill construction. Sources of fill used included local soil and quarry rock during early reclamation, building debris dumped after the 1906 earthquake, and dredged sand during construction of much of Treasure Island and Alameda.

In general, what underlies bay fills is predominantly relatively weak clay materials that increase in strength with depth and degree of consolidation. The majority of bay fills, being placed prior to the 1960s, had little engineering and controls. In many instances, the limited, more recently engineered fills with improved construction standards overlie the older, less controlled fill. Therefore, with the exception of specific improved sites or locations with only recent filling, prevalent unconsolidated, poorly controlled fills overlying soft native soil materials create generally weak soil conditions in the bay fringe areas of the project area. Engineering and construction of transportation and other facilities in these areas have to compensate for these often less than desirable foundation conditions.

3.2.2 GROUND SHAKING POTENTIAL

The shaking severity levels map, Figure 3.4, shows that a majority of the SLR area is identified with a violent shaking severity rating. The only exceptions are a few small locations at the most inland portion of Union City in southern Alameda County, which are out of the bay fill area. These areas are mapped with a strong shaking severity rating. Locations generally expected to experience the greatest severity of earthquake shaking are those with thick soil deposits and fill (including, in particular, weak bay mud

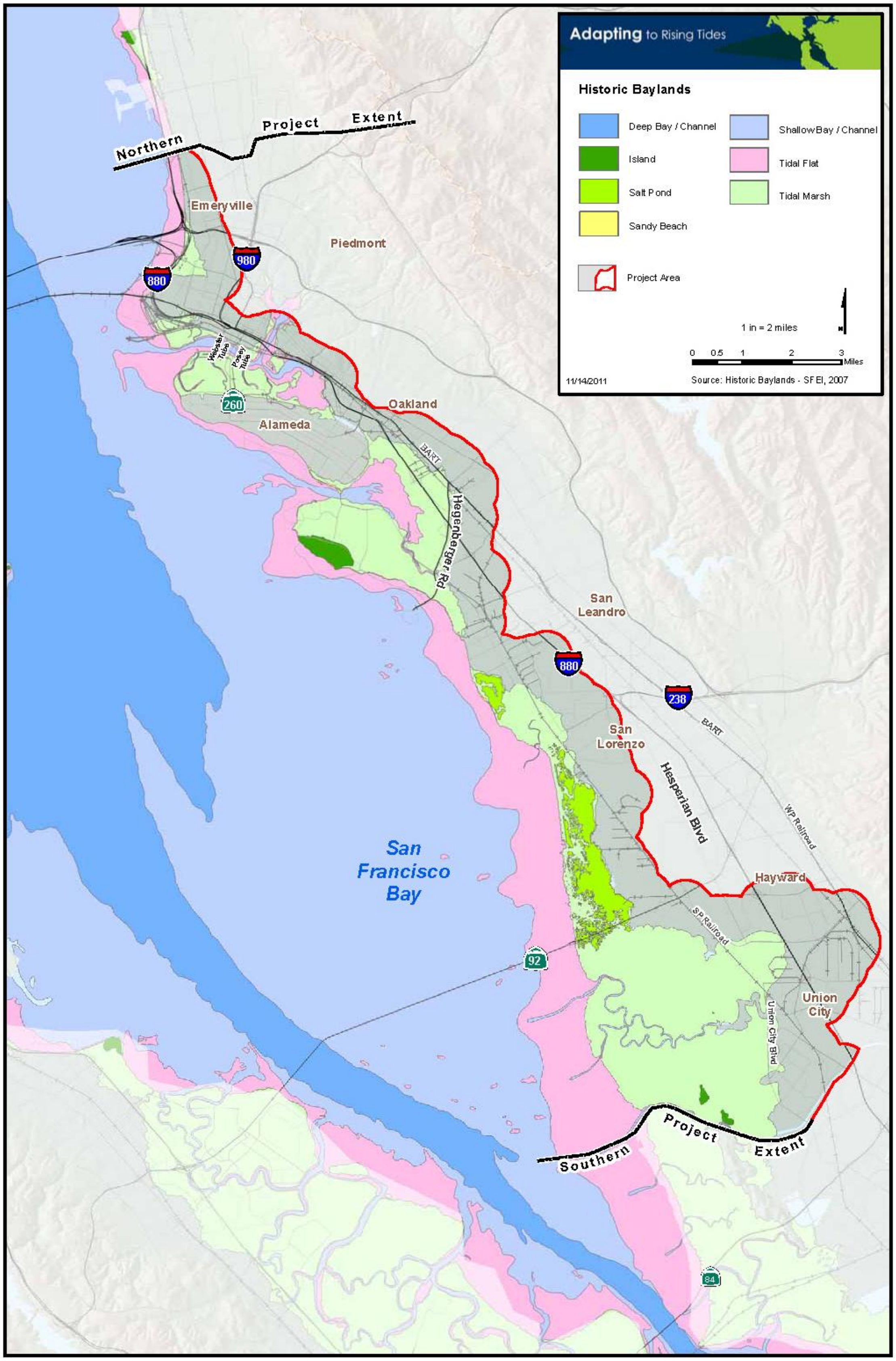

Figure 3.2 Historical Baylands

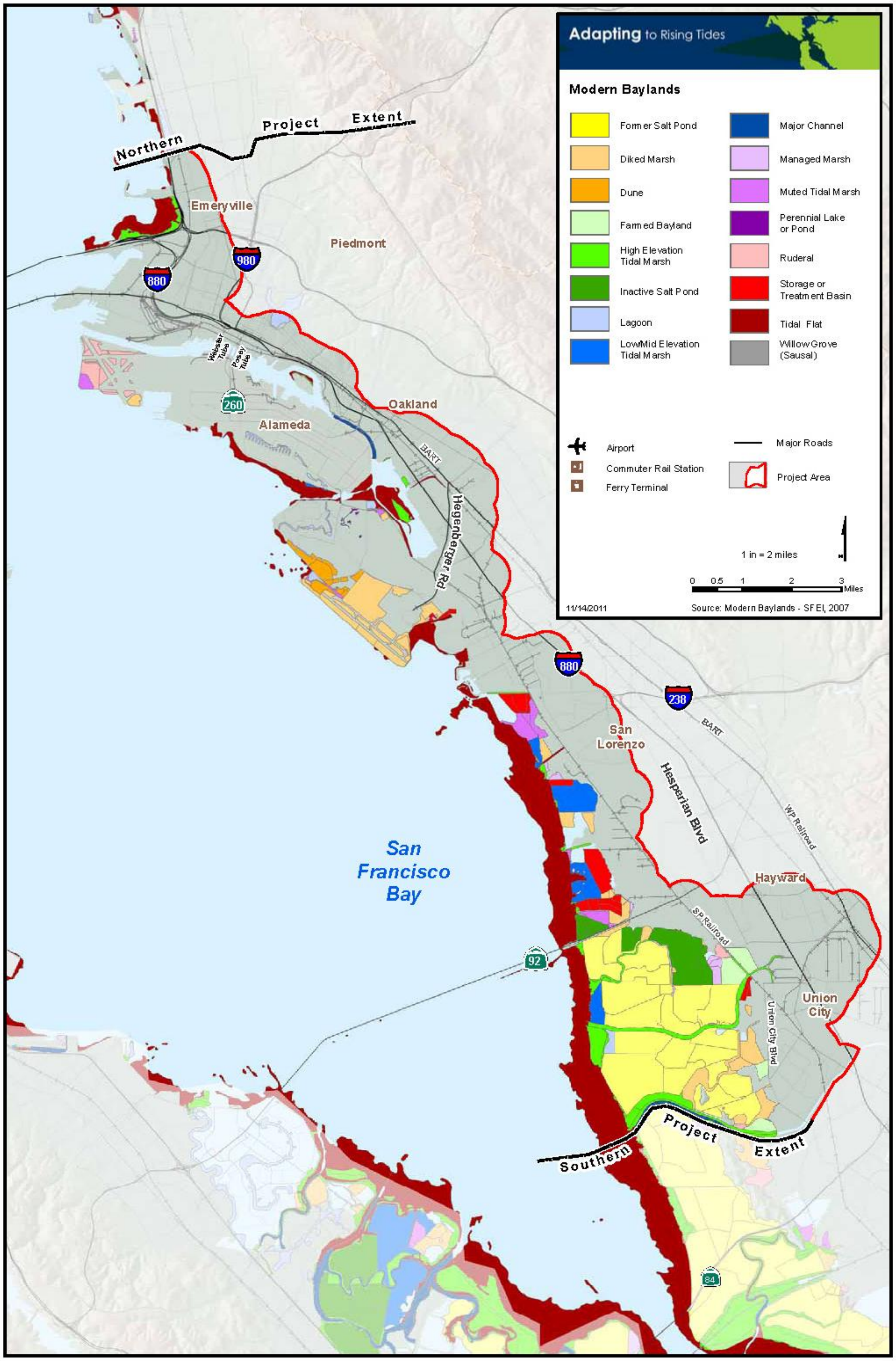

Figure 3.3 Modern Baylands

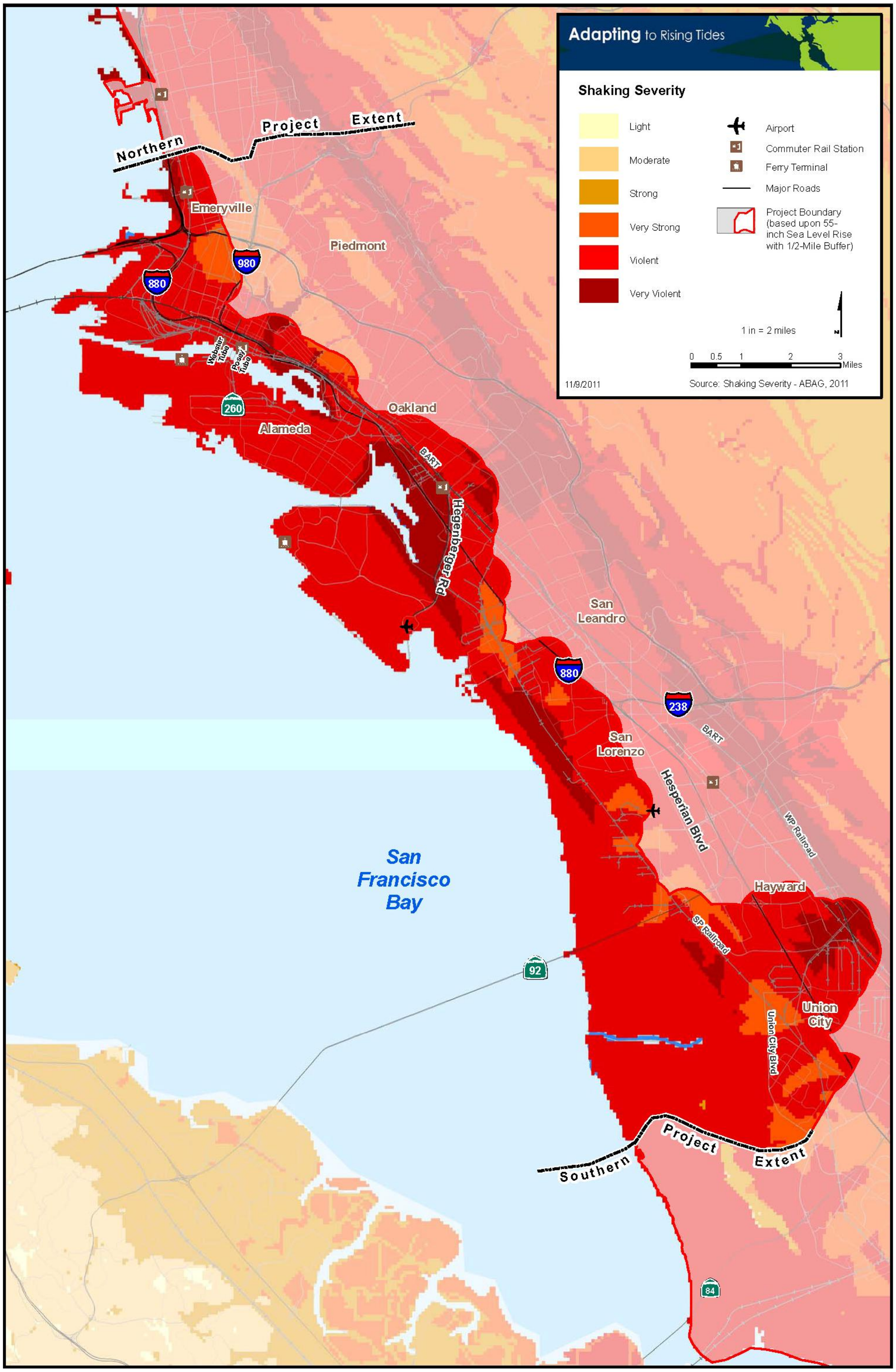

Figure 3.4 Shaking Severity

materials), which can amplify ground shaking to the surface. Structures less compatible with these ground motions require compensation in their engineering and construction.

However, of primary importance to this study is any amplification of seismic vulnerability caused by SLR. This may occur in the form of increased local ground motion at locations that see an increase in liquefaction potential due to rising ground water as a result of SLR. However, it is assumed to be most prevalent in regards to the direct effect of liquefaction and associated lateral spreading. The potential adverse effects of lateral spreading on transportation structures will be further discussed in section 3.3 Seismic Vulnerability From SLR Direct Inundation And Indirect Groundwater Rise.

3.2.3 LIQUEFACTION POTENTIAL

The liquefaction susceptibility map, Figure 3.5, shows that the northern portion of the project area is identified with a very high liquefaction susceptibility rating. In particular, the Emeryville, Oakland, and Alameda waterfront and Oakland International Airport fill areas are believed to have sandy fills with greater susceptibility to liquefaction. To the south, most of the project area in San Leandro, Hayward, and Union City is identified with a moderate liquefaction susceptibility rating.

Soil liquefaction usually has the greatest potential in clean, loose, saturated, uniformly graded silt and fine sand deposits. Liquefaction susceptibility increases as a function of less fine material content in sand/gravel materials, lower density, and greater degree of saturation. The liquefaction phenomenon occurs when the susceptible soils lose their strength with seismic shaking and increased pore water pressure during an earthquake. Coarser, gravelly soils and finer, more cohesive soils, particularly silts and silty clays, can also be vulnerable to liquefaction.

The large, sandy waterfront fills in Emeryville, Oakland, and Alameda were mostly placed after 1906 (Holzer et al. 2006) and were therefore not subjected to shaking from the 1906 earthquake. A lack of awareness of liquefaction as a seismic hazard resulted in these fills typically being placed in a manner similar to that used for many of the pre-1906 fills in San Francisco. Therefore, in general, they can be expected to perform poorly when shaken strongly by future large earthquakes on the major Bay Area faults (Holzer et al. 2006). Although ground shaking from the Loma Prieta earthquake was modest in areas underlain by East Bay fills, liquefaction was widespread with significant damage, including at the Port of Oakland, Oakland International Airport, San Francisco-Oakland Bay Bridge toll plaza, Alameda Naval Air Station, and Bay Farm Island (Holzer et al. 2006). When it comes to development of a specific site for construction of transportation-related or other types of facilities and structures, site-specific investigations will be conducted to establish liquefaction susceptibility and identify associated site improvements needed or the need for a more detailed investigation of liquefaction potential that must accompany the engineering and construction of the project.

3.2.4 GROUNDWATER

Groundwater and soil saturation play a significant role in seismic vulnerability due to their role in establishing conditions that lead to liquefaction caused by earthquake shaking. Relatively high groundwater levels exist in the relatively flat terrain along the bay margins and within the SLR area. This condition in itself presents special circumstances that must be compensated for in the engineering and construction of certain structures. A recent USGS study of the hydrogeology of aquifers beneath the San Leandro and San Lorenzo areas in the central portion of the project area shows groundwater essentially at sea level close to the bay and rising inland, toward the east (Izbicki et al. 2003). The study also acknowledges that groundwater levels near the bay also respond to tidal fluctuation, with associated pressure changes (Izbicki et al. 2003). For the scenario of end of century SLR considered by the pilot

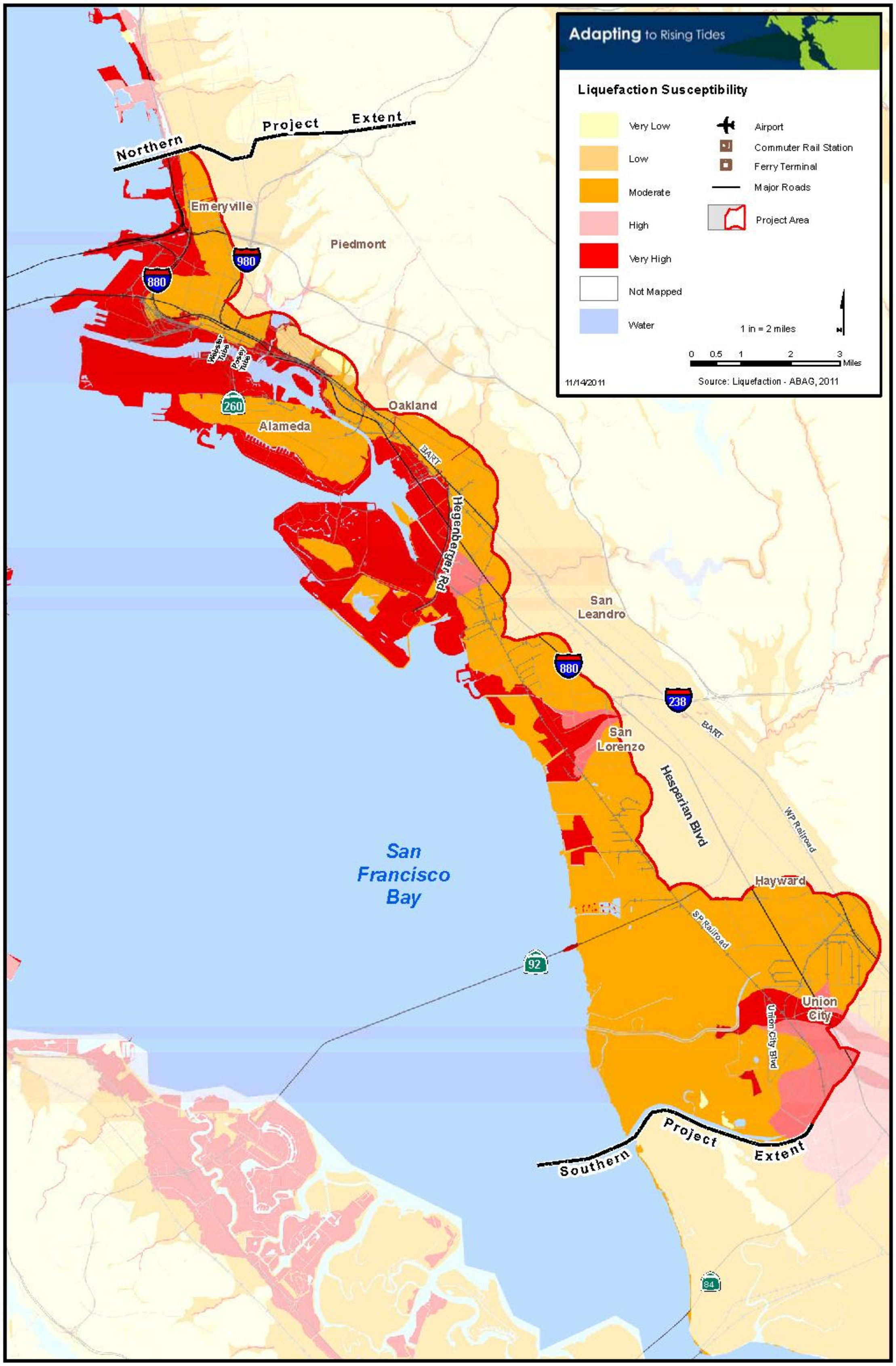

Figure 3.5 Liquefaction Susceptibility

project, it would seem that already high groundwater levels near the bay would rise over the long term essentially in line with the magnitude of the SLR expected.

3.3 Seismic Vulnerability from SLR Direct Inundation and Indirect Groundwater Rise

For the transportation assets being evaluated, the obvious direct effect of rising sea level is inundation. The primary indirect effect on seismic vulnerability of the transportation assets is considered to be the groundwater-level rise associated with the direct effect from increased tidal levels with SLR.

In general, bridges in California built after 1972, following the 1971 Sylmar (LA area) earthquake, were designed to a more modern code, which better addressed the actual seismic demands and detailing requirements. Incremental advancements in seismic design and detailing, especially following the 1987 Whittier Narrows, 1989 Loma Prieta and 1994 Northridge earthquakes, have continued to this day. Beginning in the early 1990s, Caltrans began a more aggressive (phase 2) seismic retrofit program to strengthen vulnerable bridges. Cities, Counties and other agencies also began retrofitting their bridges. The intent of these retrofits is to increase the seismic performance of a bridge to meet a “no collapse” criteria (major damage is acceptable provided the bridge will not collapse). A majority of the road assets in this study were built before the modern codes.

However, of primary importance to this study is any amplification of seismic vulnerability caused by SLR, which is assumed to be most prevalent in regards to liquefaction and associated lateral spreading (tendency of soil layers above liquefiable layers to “flow” downhill). This is particularly pertinent in zones where soils underlying a transportation facility that are in the classification of liquefiable soils but are currently above the water table, become saturated due to the rising ground water associated with SLR.

Although it was standard practice to evaluate the potential for liquefaction during the Phase 2 seismic retrofit program, lateral spreading was typically not accounted for. Caltrans now requires that new transportation structures consider the potential for this effect. Therefore, this study area contains many structures that are currently vulnerable and SLR will result in additional structures becoming vulnerable.

Liquefaction-induced lateral spreading is usually considered to occur just following a seismic event. Once the ground shaking from the earthquake has caused the underlying layer to liquefy, the overlying “crust” loses its resistance to moving down slope. This moving soil can result in tremendous pressure on bridge foundations causing them to fail or displacing them to the point that the bridge deck could collapse.

The above discussion has focused on bridges; however, the study area includes miles of raised roadway on embankment fills. Such embankment fills are even more susceptible to lateral spreading when the overlying soil can spread in two directions. Although, failure of an embankment will not result in as catastrophic damage and potential for loss of life as a bridge failure, such failures can be costly to repair. More importantly, such failure could result in the loss of a critical evacuation/emergency route following the earthquake. Figures 3.6 and 3.7 illustrate the effects of lateral spreading

3.3.1 INCREMENTAL SEISMIC IMPACT/FAILURE RISK TO SHORELINE ASSETS FROM SLR

In the event of SLR, it is obvious that shoreline protection systems, either existing or new, would be required to mitigate the effects of inundation. The inundation maps in Chapter 6 show that the shoreline assets would protect the transportation assets to a certain level under the midcentury and end-of-century SLR scenarios. This protection is provided by a range of shoreline assets, shown in Chapter 2, from

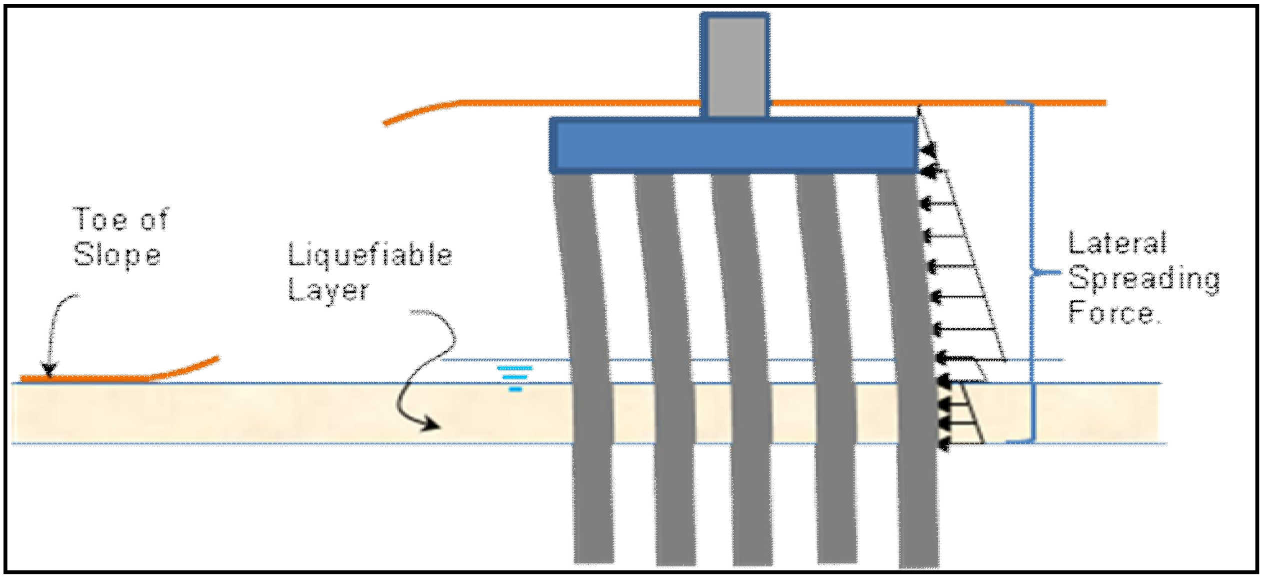

Figure 3.6 Force on Foundation Due to Lateral Spreading

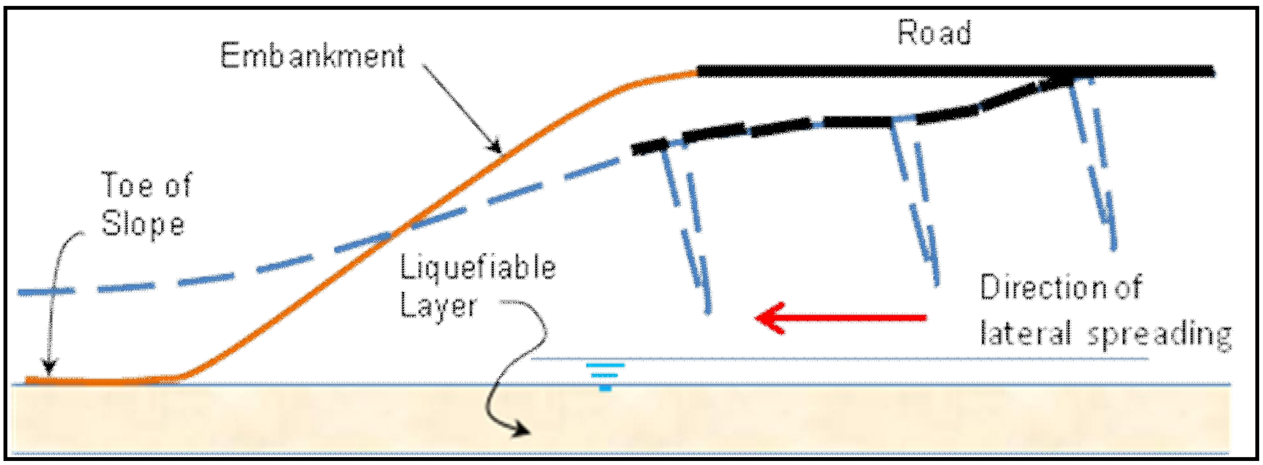

Figure 3.7 Slope Failure Due to Lateral Spreading

engineered structures, such as levees, flood walls, and revetments, to natural beaches and wetlands. However, regardless of the existing type and location of shoreline protection, the inundation mapping for the maximum 55 inches scenario with the most severe flood and wave conditions considered, indicates that nearly all the shoreline assets would be inundated or submerged.

It is assumed that any new shoreline protection installed to protect against SLR and inundation would be engineered and constructed to current standards and minimum regulatory requirements and thus would likely adequately protect against failure and resulting inundation as a result of a seismic event. However, any new loading or adverse conditions imposed, such as from SLR, would at a minimum reduce the level of protection or safety factor against failure, up to creating a failure condition. These more marginal situations under seismic conditions for shoreline protection, specifically resulting from SLR, are presented below:

- **Reduced stability** for levees, dikes, walls, and other water retention structures would be one of the most direct effects of SLR on these engineered shoreline assets. Increased water level loading against the structure reduces the level of stability by a combination of increased driving force of the higher water pressure and possible decreased resisting force with increased buoyancy of the restraining mass. Without a counteracting enhancement of the shoreline protection structure cross section for increased stability, the incremental increased tidal loading from SLR would correspondingly reduce the structure safety factor for static and seismic stability.

- **Increased liquefaction potential** would be expected in cases where shoreline assets rest on or contain potentially liquefiable materials that, with SLR, would be subjected to an increased degree of saturation and higher pore pressures or would be introduced to groundwater and saturation. This would result in previously nonliquefiable materials becoming susceptible to the phenomenon. The result of increased liquefaction potential, as described above, would be reduced stability, with loss of material strength in the susceptible materials due to seismic shaking.
- **Increased lateral spreading potential** would be expected in cases where shoreline assets with geometry that allows lateral translation, which would already be subject to compromise due to liquefaction during earthquakes, would be subject to increased lateral forces associated with higher retained water levels. This would apply to, for example, levees, bulkheads, revetments, and other shoreline protection features with slopes or retaining walls. Lateral spreading is one of several types of ground deformation, others including seismic settlement and bearing capacity failure, that can result from liquefaction and associated material strength loss. With the added adverse forces from SLR on shoreline assets, they would be more vulnerable to damage from lateral spreading as liquefaction will have already led to instability and ground deformation.

3.3.2 INCREMENTAL SEISMIC IMPACT/FAILURE RISK TO TRANSPORTATION ASSETS FROM SLR

Aside from the obvious unacceptable effect on transportation assets from inundation, the seismic vulnerability of and potential failure risk to transportation assets associated with SLR-caused groundwater-level increase revolves around liquefaction potential and the associated resultant adverse conditions it creates. As discussed earlier, the bay margins within the SLR area, which contain the materials most susceptible to liquefaction, often have the shallowest groundwater conditions.

The transportation assets being evaluated that fall within both the SLR area and the high to very high liquefaction susceptibility mapped areas would generally be considered the most vulnerable to increased seismic impact associated with the indirect groundwater rise effect. Thus, most vulnerable would be structures in the SLR areas of the Emeryville, Oakland, and Alameda waterfront and Oakland International Airport fill areas. Less vulnerable are assets in the southern Alameda County SLR areas. The liquefaction-oriented conditions resulting from seismic events, exacerbated by higher groundwater levels, specifically resulting from SLR, are discussed below:

- **Increased liquefaction potential** under the indirect SLR effect of groundwater-level rise would be expected where additional and shallower zones of liquefaction-susceptible materials would be subjected to saturation. A recent liquefaction potential study for various types of surficial geologic units, including alluvial fan deposits in the San Francisco Bay region and sandy artificial fills along the Oakland waterfront, acknowledges that the severity of liquefaction is considered proportional to a number of factors, including cumulative thickness of liquefied layers and proximity of liquefied layers to the ground surface (Holzer et al. 2011). The study developed liquefaction probability curves for the various types of surficial geologic units considered, as a function of earthquake magnitude and peak ground acceleration. It also developed these curves for different water table depths to demonstrate the effect of depth to groundwater. For the alluvial fan and sandy artificial fill cases directly applicable to the SLR study area, the curves generally represent an increase in liquefaction probability on the order of 1.5–3 times higher, for a water table depth at about 5 feet, compared to a water table condition at a depth of about 15 feet (Holzer et al. 2011). Therefore, based on this study, the incremental increased adverse effect of liquefaction due to groundwater-level rise appears quite significant.

- **Increased lateral spreading potential** would be expected to go hand in hand with the increased liquefaction potential from the indirect groundwater-level rise effect in situations where lack of confinement or sloping geometry would allow lateral translation upon liquefaction and strength loss. The increased lateral forces imposed on various types of transportation asset and their foundations can be significant, and the incremental increased forces imposed by the additional indirect groundwater-level rise effect exacerbating the lateral spreading potential could very likely exceed the original structural design loading limitations.

3.4 Recommended Refinements to the FHWA Conceptual Model

A seismic vulnerability assessment is not part of the conceptual FHWA risk assessment model given that it is very specific to bay area geology. Therefore the lessons learnt and recommendations identified below are not specific to the model per se, but may be of use for other projects also in an area of high seismic vulnerability.

3.4.1 LESSONS LEARNED

DATA COLLECTION

Compared to the detailed work establishing the transportation and shoreline assets and mapping the various SLR and other conditions, the scope of the seismic vulnerability assessment was very limited and qualitative in nature. The scope did not include identifying the seismic vulnerability of various specific categories and types of transportation and shoreline assets. The assessment was quite broad and generalized, which seemed somewhat inconsistent with the level of detail for the rest of the assessment work.

DATA AVAILABILITY

Some additional background data for existing groundwater levels in the study area would have been helpful to address the indirect effect on seismic vulnerability associated with anticipated groundwater-level rise with SLR.

3.4.2 RECOMMENDATIONS FOR FUTURE APPLICATIONS

For a more focused and effective evaluation, it would be a more streamlined process to assess the seismic vulnerability once the initial asset identification and mapping had been completed.

3.5 References

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Holzer, T., Blair, J., Noce, T., and Bennett, M., 2006. Predicted Liquefaction of East Bay Fills During a Repeat of the 1906 San Francisco Earthquake, Earthquake Spectra, Volume 22, No. S2, pp. S261-S277, April 2006.

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Izbicki, J., Borchers, J., Leighton, D., Kulongoski, J., Fields, L., Gallowaw, D., and Michel, R., 2003. Hydrogeology and Geochemistry of Aquifers Underlying the San Lorenzo and San Leandro Areas of the East Bay Plain, Alameda County, California, U. S. Geological Survey Water-Resources Investigations Report 02-4259.

Climate Science and Climate Impacts

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4 Climate Science and Climate Impacts

4.1 Introduction

A summary of local- and regional-level climate information has been compiled that provides historical, current, and projected conditions. This chapter provides an overview of the climate change–related information. More detailed background information is presented in Appendix B.

This chapter also describes the preparation of new inundation maps for the two sea level rise (SLR) scenarios evaluated for the project: specifically, 16 inches (40 centimeters [cm])[2] by midcentury and 55 inches (140 cm) by the end of the century, consistent with the *State of California Sea-Level Rise Interim Guidance Document* (CO-CAT 2010). The two SLR scenarios are also compatible with previous SLR planning efforts in San Francisco Bay led by the San Francisco Bay Conservation and Development Commission (BCDC) and the U.S. Geological Survey (USGS), which formed the foundation for this effort.

The new inundation maps were used to assess the depth of inundation along the transportation assets to inform the vulnerability rating of the transportation assets (Chapter 5) and to evaluate the potential for overtopping along the Alameda County shoreline to inform potential adaptation strategies (Chapter 7). This process is described in Figure 4.1. The inundation maps and the related products are presented in Chapter 6, and the detailed methodologies are presented in Appendix B. This chapter also provides a list of the major caveats and uncertainties associated with the inundation maps. The analysis performed to develop the inundation maps is appropriate for a high-level planning effort and is not intended to represent, or take the place of, detailed engineering analyses. The process used for the analysis is described in Table 4.1.

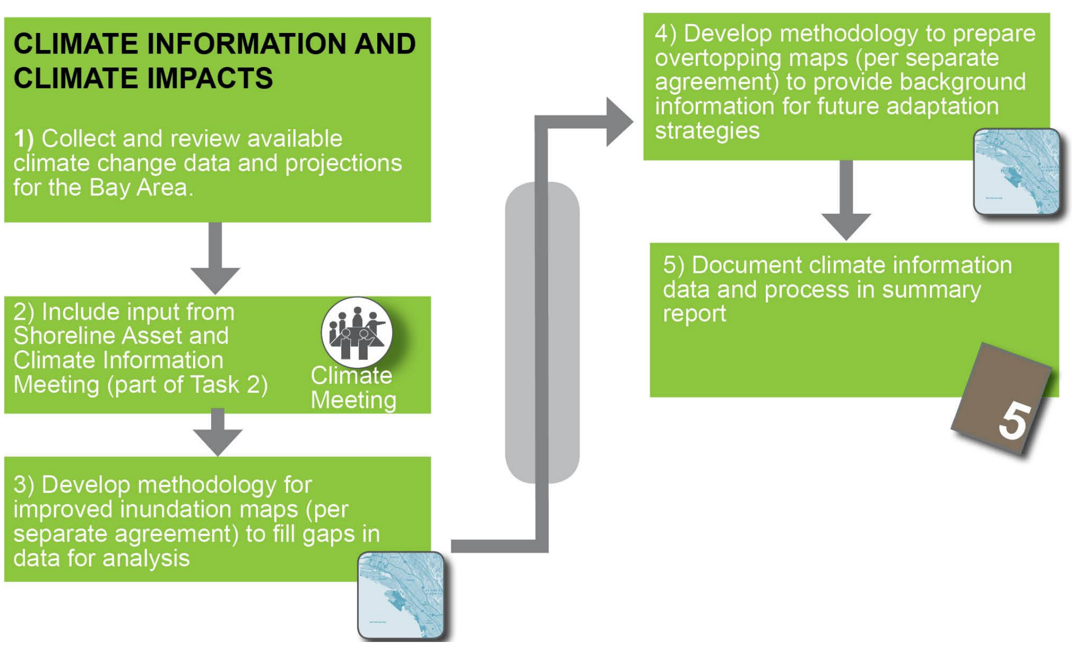

Figure 4.1 Climate Science and Climate Impacts Process

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2 Due to the international data referenced in this chapter, both metric and imperial units are used, to be consistent with the research produced.

Table 4.1 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: California Ocean Protection Council (CO-CAT) 2010.

*Note: Rahmstorf and Vermeer's paper presents values using 1990 as a baseline. Here the values are adjusted by subtracting1.3 inches / 3.4 centimeters, which represents 10 years of SLR that has already occurred, at an average rate of 0.1 inches / 3.4 millimeters per year.

4.2 Climate Information Summary

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). A detailed summary of climate information is presented in Appendix B.

Climate change is already affecting California. Sea level has risen by as much as 7 inches along the California coast over the last century, increasing erosion and adding pressure to the state's infrastructure, water supplies, and natural resources (California Natural Resources Agency 2009). During this period, and despite annual variations in weather patterns, California has also seen a trend of increased average temperatures, more extreme hot days, fewer cold nights, longer growing seasons, less winter snow, and earlier snowmelt and rainwater runoff (California Natural Resources Agency 2009).

An increase in the rate of SLR is one of the primary effects of climate change (Knowles 2009). SLR has the potential to cause major damage to residential, commercial, and industrial structures in low-lying areas near the shoreline, as well as to important habitats and wildlife resources. For this reason, planning for SLR has become a higher priority in California. Through the use of innovative efforts to identify vulnerable areas, California will be better prepared to protect communities and the environment from the potentially devastating impacts of SLR.

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). Table 4.1 provides an overview of the SLR projections provided in the Ocean Protection Council's interim guidance document. The two SLR scenarios selected for the pilot project represent a high-end estimate for midcentury (16 inches of SLR) and a midrange estimate for the high-emission scenario for the end of the century (55 inches of SLR). These two SLR scenarios are also compatible with previous SLR planning efforts in San Francisco Bay led by BCDC and USGS.

In addition to SLR, scientists predict that global warming will increase the frequency of major storms. With increasing storm intensity, the potential exists for storm-generated waves to increase in height, resulting in an overall change in the San Francisco Bay wave climate. When large storm events coincide with high tides or extreme coastal water levels, there is a greater potential that existing shore protection infrastructure would be overtopped, resulting in a potentially larger inundation area. Therefore, a thoughtful evaluation of the risks associated with SLR would include an assessment of extreme coastal water levels and increasing wave heights.

4.3 Inundation Mapping

This chapter presents the methodology for developing the new SLR inundation maps produced for the pilot project. Two modeling efforts were leveraged for this study, and this chapter, along with the detailed methodology presented in Appendix B, documents how the model output from these efforts was used to develop the inundation maps. In addition, the major caveats and assumptions associated with the inundation maps are described.

4.3.1 INUNDATION MAPS

Six inundation scenarios were evaluated as part of this effort. Each SLR scenario—16 inches (40 cm) by midcentury and 55 inches (140 cm) 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. The three storm/tide conditions were selected as they represent a reasonable range of potential inundation conditions. The inundated area associated with high tides under each SLR scenario is representative of the area that would be subjected to frequent or permanent tidal inundation. This level of inundation could correspond to slow and regular degradation of infrastructure, including shoreline protection. Although storm conditions represent a lower frequency event, they come with a larger potential flooded area, with deeper flooded depths, higher velocities, and a greater likelihood of wind-driven waves that could overtop existing shore protection infrastructure. Most of the near-term damage that SLR is expected to cause on developed areas is from storm conditions that occur at the same time as high tides (SPUR 2011).

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

The inundation maps are presented in Chapter 6, including overall maps for the project area and five focus area maps that provide a more detailed look at the inundated depth and extent overlain with the selected transportation assets. The detailed methodologies used to create the inundation maps are presented in Appendix B. New inundation maps were created for the pilot study region for several reasons:

- The previous inundation maps created by Knowles (2009, 2010) for the San Francisco Bay area did not include depth of inundation. The new inundation maps provide the extent of inundation for each scenario, as well as the depth of inundation for the entire inundated area. The depth of inundation along the shoreline assets and at the transportation asset locations was considered to be an important factor in assessing vulnerability to SLR.

- The previous inundation maps did not account for the level of flood protection provided by the region's flood protection levees and other shoreline protection structures. Inundation maps that more accurately characterized the existing shoreline assets would provide a better understanding of the potential risk to future inundation.
- The previous inundation maps did not account for wind waves. Wind wave generation within San Francisco Bay is an important process 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 National Oceanic and Atmospheric Administration Coastal Services Center to exclude low-lying areas that are below the inundated water surface elevation but would not be hydraulically connected to the inundated areas.
- The previous study relied on older Light Detection and Ranging (LIDAR) elevation data with less vertical and horizontal accuracy. This study benefits from the 2010 LIDAR data collected by USGS for South San Francisco Bay.

4.3.2 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. The detailed methodology used for the shoreline overtopping potential analysis is presented in Appendix B.

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. Chapter 6 presents the resulting overtopping potential maps for each SLR scenario and storm/tide condition, including a detailed look at five focus areas within the pilot region.

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 results of the analysis by system are presented in Chapter 6. Each figure shows three panels, representing the MHHW, 100-yr SWEL, and 100-yr SWEL + wind waves scenarios, to highlight the progression of overtopping under the three storm/tide conditions.

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 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 less than the 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.

4.3.3 TRANSPORTATION ASSET INUNDATION POTENTIAL

In a manner similar to that described in Section 4.3.2, the depth of inundation information was extracted along the transportation assets described in Chapter 2 to inform the vulnerability of the transportation assets under the two SLR scenarios and the three storm/tide conditions. The results of this assessment are described in more detail in Chapter 5.

4.3.4 UNDERLYING ASSUMPTIONS AND CAVEATS

The inundation maps are intended only 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 the following 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 impact flood water conveyance are derived from the USGS 2010 LIDAR at a two meter horizontal grid resolution. Although this data set represents the best available topographic data, and the data has undergone a rigorous QA/QC by a third party, the data has not been extensively ground-truthed. Levee crests and other topographic features may be over or under-represented 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.

4.4 Recommended Refinements to the FHWA Conceptual Model

This section provides feedback on the FHWA conceptual model and its application in the selected Alameda County subregion in terms of the climate change data collection process and the development of the inundation maps.

4.4.1 CLIMATE SCIENCE DATA GATHERING

The San Francisco Bay region benefits from a wealth of available climate science data, including sea level rise inundation mapping completed by the USGS (Knowles 2009, 2010) before the initiation of this pilot study. However, the existing inundation maps did not provide depth of inundation within the study area, and the project team believed that the depth of inundation under various SLR scenarios was a critical element for assessing the vulnerability of transportation assets to climate change. The project produced new inundation maps, and associated products such as the shoreline overtopping potential, that were not anticipated at the outset of the project and were therefore not included within the project schedule.

4.4.2 LESSONS LEARNED

The following lessons were learned as part of the pilot project with respect to the inundation mapping effort:

- The project team was able to develop new inundation maps for the project in a cost-effective manner using data leveraged from other studies: the previous USGS (Knowles 2009) SLR study, the FEMA San Francisco Bay Coastal Hazard Analysis study, and the USGS 2010 LIDAR. If these data sets were not available to the project, the vulnerability analysis of the transportation assets would have been more limited.
- The information available from existing inundation maps can vary greatly, both in form and content. The project team found that the most important piece of information gleaned from the inundation mapping effort was the depth of information.
- Inundation maps should be developed using topographic data that is capable of resolving the shore protection assets, such as flood protection levees. Accurately characterizing the shore protection assets lends greater credibility to the maps, and therefore the entire vulnerability and risk assessment process.
- The mapping exercise was very time consuming, in particular extracting the relevant depth information for each transportation asset at for each SLR scenario.

4.4.3 RECOMMENDATIONS

Recommendations for the climate science and climate impacts component of the process include the following:

- Depending on the geographic area where the risk assessment is being carried out, it may be sufficient to use existing climate science information. However, this study shows how further mapping of the likely climate impacts is an integrated piece of understanding transportation asset vulnerability (the model could highlight that there may need to be considerable effort spent on categorizing shoreline assets, and undertaking new inundation mapping (and overtopping analysis) for projects addressing sea level rise). This mapping work was important to help assess the vulnerability of the transportation assets.
- An indication of the time consuming nature of additional mapping should be provided in the model.
- It should be noted in the model that climate science is continually evolving so vulnerability and risk assessments will also need regular updating as new modeling becomes available.

4.5 References

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Vulnerability and Risk Assessment

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5 Vulnerability and Risk Assessment

5.1 Introduction

Understanding the level of vulnerability of an asset to climate impacts is a valuable part of decision making and policy development for future adaptation, as it provides a basis for establishing priorities. For this project, the vulnerability assessment identifies the degree to which the assets would be affected by sea level rise (SLR). Section 5.2 describes the vulnerability assessment that was carried out for the selected assets.

Risk is the potential for an unwanted outcome resulting from an event, in this case from inundation from SLR. It is determined by the product of (a) the likelihood of the impact and (b) the consequence of the impact. The likelihood of an impact is, in part, a function of the likelihood of the impact (SLR) occurring. "Consequence" refers to the significance or impact to the wider region of the inundation of an asset due to SLR.

Section 5.3 describes the risk assessment that was carried out for the selected assets. During the risk assessment, (1) the vulnerability of the selected assets to SLR was reviewed in order to screen out assets that were less vulnerable to projected climate effects; (2) the likelihood of inundation occurring from SLR was assessed; (3) the consequence of the impact was reviewed, not just in terms of what the impact would do to a particular asset, but in terms of how it would affect the surrounding community and beyond; and (4) the risk rating of the consequence and likelihood occurring was determined. Section 5.4 contains the risk profiles summarizing all of the information collected on the assets that were developed as a result of the risk assessment. The process is outlined in Figure 5.1.

5.2 Vulnerability Assessment

5.2.1 INTRODUCTION

The vulnerability of an asset is related to its potential for, or its susceptibility to, damage. Vulnerability to climate change is often assessed in terms of exposure, sensitivity, and adaptive capacity. This analysis used definitions from the Intergovernmental Panel on Climate Change (IPCC 2007) for the following terms:

- **Vulnerability** "*is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes."*
- **Exposure** *"is the nature and degree to which a system is exposed to significant climatic variations."* (For this project, this is SLR and is measured by depth of inundation at midcentury and at the end of the century.)
- **Sensitivity** *"is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli."* (For this project, this is the physical condition of the asset. The worse the condition of the asset, the larger the magnitude of an adverse reaction to SLR is assumed.)
- **Adaptive capacity** "is the ability of a system to adjust to climate change to moderate potential damages, to take advantage of opportunities or cope with the consequences" (IPCC 2001, also referenced in the 2009 California Climate Adaptation Strategy [California Natural Resources Agency 2009). (For this project, one critical aspect of adaptive capacity is the ability to divert traffic onto alternative routes.)

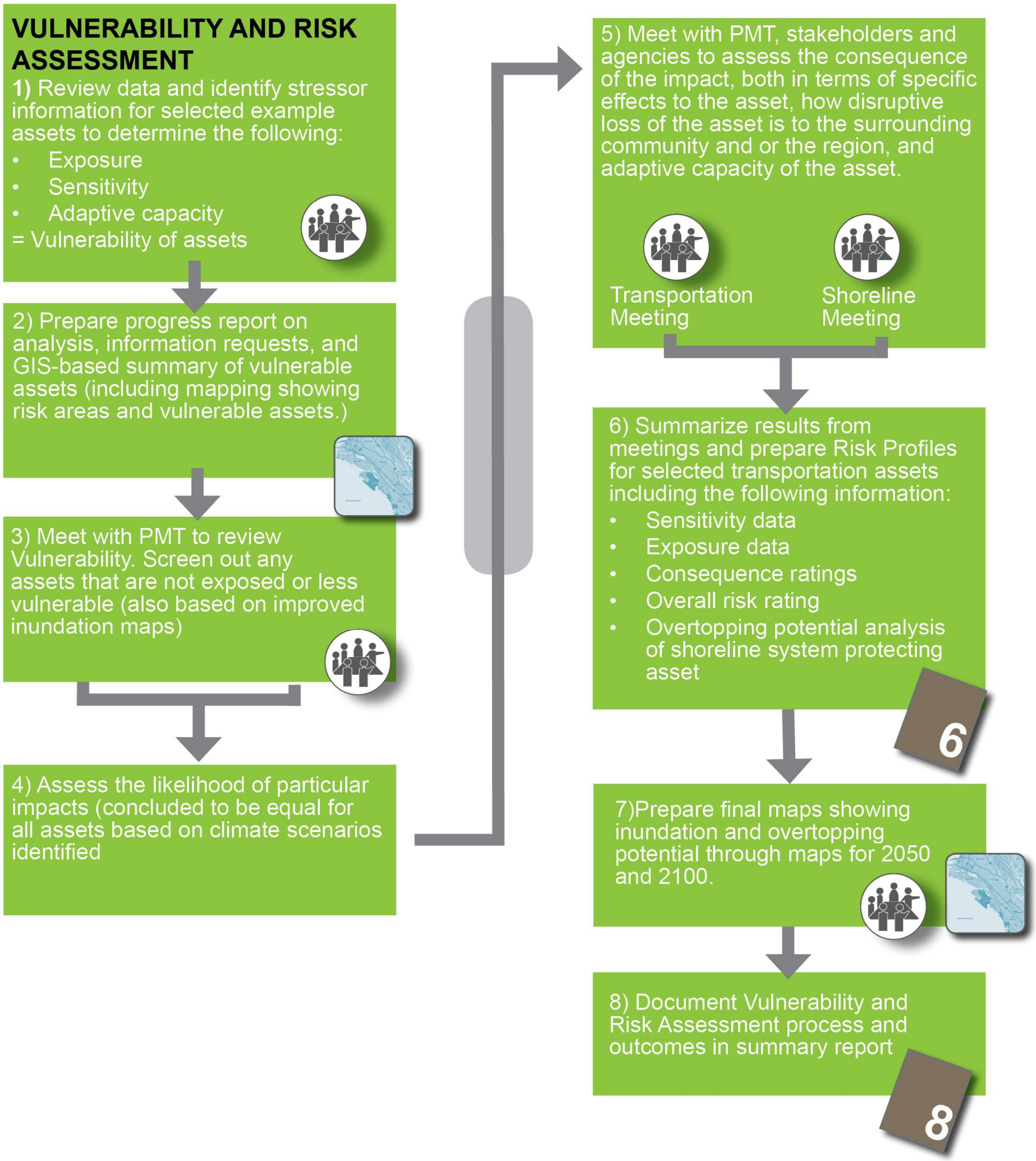

Figure 5.1 Vulnerability and Risk Assessment Process

Exposure to SLR is the primary indicator of vulnerability for this study as only assets exposed to SLR were included in the assessment, and good information was available to illustrate the potential depth of inundation that the asset would be exposed to. Due to lack of readily available information on the assets, the sensitivity or condition data was not as complete. For other climate change vulnerability assessments, the sensitivity component may be a more important indicator. Adaptive capacity must be considered carefully as part of any vulnerability assessment, as even with adaptive capacity, exposed assets can remain vulnerable. Adaptive capacity (specifically, the ability to divert traffic onto alternative routes for this project) is included as part of the vulnerability assessment. Generally, an asset that is more exposed and sensitive to a climate stimulus, condition, or hazard will be more vulnerable, whereas a system that has more adaptive capacity will tend to be less vulnerable.

In addition to setting priorities, a vulnerability analysis also provides valuable information that will aid in determining which adaptation strategies may work best, as well as determining the potential points of intervention for implementing those strategies (such as during replacement, or seismic retrofit). It also helps to identify which agencies will need to be involved in the development and implementation of those strategies as well as a variety of other issues.

Vulnerability	=	Exposure	+	Sensitivity	+	Adaptive Capacity

5.2.2 EXPOSURE TO SLR

Three maps each were produced for the 16-inch (midcentury) and 55-inch (end-of-century) SLR scenarios, as described in Chapter 4, describing six possible exposure scenarios for each asset. These maps were used to assess whether or not the asset was inundated by SLR under the different scenarios. If the maps showed a selected asset inundated at midcentury, it automatically received a high exposure rating. This midcentury exposure rating guided the overall exposure rating. If an asset would be inundated at midcentury under the 100-year stillwater elevation (SWEL) scenario, then a medium exposure rating was assigned, as it is a less likely scenario that would affect an asset on a more temporary basis. If an asset would be inundated at the end of the century under either the mean higher high water (MHHW) or 100-year SWEL scenario, it received a medium exposure rating. Note that the elevation of an asset above inundation level was not considered important for this rating, as any inundation could potentially weaken the foundations or supports of an elevated structure, therefore still placing it at risk. An asset that is inundated only under either of the wind wave scenarios received a low exposure rating. Table 5.1 and Table 5.2 outline the exposure rating assigned to each scenario for midcentury and the end of the century, respectively. Refer to Appendix B for a discussion of how the inundation depths were extracted from maps.

Table 5.1 Midcentury Exposure Rating

Midcentury Scenario	Exposed to:	Metrics	Exposure Rating		
			High	Medium	Low
16” SLR + Mean Higher High Water (MHHW)	High tide levels	Depth & Extent	X		
16” SLR + stillwater elevations (100-yr SWEL)	Extreme high water levels with a 1-percent return interval	Depth & Extent		X	
16” SLR + stillwater elevations (100-yr SWEL) + wind wave	Extreme coastal storm event with wind waves	Extent only*			X

* The 100-year SWEL plus wind wave provides only the extent of inundation. The extent of inundation inland into Alameda County is large, and the physics of wave propagation and dissipation over land were not fully included in the analysis used to develop these maps. The limitations of the wind wave assessments and the inherent uncertainties are described in Chapter 4. Wind and wave assessments are being developed for San Francisco Bay Coastal Hazard Analyses currently underway, being performed for FEMA Region IX of the San Francisco Bay shoreline, and thus more information on this topic may be available for future subregion assessments.

Table 5.2 End-of-Century Exposure Rating

End of Century			Exposure Rating		
Scenario	Exposed to:	Metrics	High	Medium	Low
55" SLR + Mean Higher High Water (MHHW)	High tide levels	Depth & Extent		X	
55" SLR + stillwater elevations (100-yr SWEL)	Extreme high water levels with a 1-percent return interval	Depth & Extent		X	
55" SLR + stillwater elevations (100-yr SWEL) + wind wave	Extreme coastal storm event with wind waves	Extent only*			X

* The 100-year SWEL plus wind wave provides only the extent of inundation. The extent of inundation inland into Alameda County is large, and the physics of wave propagation and dissipation over land were not fully included in the analysis used to develop these maps. The limitations of the wind wave assessments and the inherent uncertainties are described in Chapter 4. Wind and wave assessments are being developed for San Francisco Bay Coastal Hazard Analyses currently underway, being performed for FEMA Region IX of the San Francisco Bay shoreline, and thus more information on this topic may be available for future subregion assessments.

5.2.3 SENSITIVITY

Sensitivity of an asset to inundation by SLR relates to both the condition and the function of an asset. This study used physical condition to evaluate sensitivity, while data related to function (goods movement, socioeconomic impact, etc.) were used to evaluate consequence. The following physical characteristics were determined to best describe the sensitivity of an asset to SLR:

- Level of use (e.g., average daily traffic [ADT] volume [cars/trucks])
- Age of facility
- Seismic retrofit status
- Maintenance (ongoing operations and maintenance [O&M]) cost
- Liquefaction susceptibility

Information was also collected on the following other physical characteristics but ultimately not used to evaluate the sensitivity of assets:

- Condition/remaining service life - It was determined that data on remaining service life does not provide a conclusive indication of sensitivity. For instance, an asset with a short remaining service life could be characterized as sensitive, because it soon must be replaced – however, once this replacement occurs, it would then count among the assets with the greatest remaining service life, and therefore least sensitive. Since the timing of the impacts of sea level rise and of future replacement or improvements is not known, it was decided not to include "remaining service life" or age as inputs to the sensitivity rating; however, where provided this information is presented in the risk profiles.
- Foundation condition - Data was requested for foundation condition, but very little information was actually collected.

The sensitivity criteria were not appropriate for all asset types and therefore, the information for those asset types was neither available nor relevant.

This condition data also provided key input for consideration of adaptation measures, particularly for the midcentury scenario. However, based on the final quality and quantity of data received on the assets, not all of the sensitivity data were used in the development of sensitivity ratings. Therefore, sensitivity ratings were developed based on the data collected and were compared within asset types. For example, the sensitivity of a roadway asset was compared with other roadway assets, not with other asset types, such as rail facilities. Overall sensitivities were therefore compared only within particular asset types and not between asset types. The approach for each asset type is described below.

ROADWAYS

For roadways (interstates/freeways and state routes and arterial, collector, and local streets), comparable data were generally available for the above-mentioned sensitivity metrics, except for foundation condition. Seismic retrofitting does not apply to all roadway segments and was not considered for rating purposes. In addition, the related metrics of age and remaining service life were not considered in the final ratings; older assets—though more sensitive at present—may be improved or rebuilt before SLR affects them, whereas newer assets—less sensitive today—may exhibit the greater sensitivity of older assets at the time when they are affected by SLR. Absent further information and analysis about the likely future lives of the assets, these data alone were not considered sufficient to provide a conclusive indication of sensitivity. The data points for the remaining 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. Table 5.3 shows a couple of examples for interstates/freeways and state routes, and Table 5.4 shows a couple of examples for arterials, collectors, and local streets. The full list of sensitivity ratings assigned for the assets reviewed can be found in Table C5.3 and Table C5.4 in Appendix C.

Table 5.3 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**
SR 92 (Clawiter Rd. to Toll Plaza)	86,000 2 pts.	$436,000 2 pts.	Medium 1 pt.	Point total:5 **L**

Table 5.4 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**
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**

TUNNELS AND TUBES, TOLL, INTERSTATE AND STATE BRIDGES, AND FERRY TERMINALS

For tunnels and tubes, toll, interstate and state bridges, and ferry terminals, there are only two or three assets for each type. In these cases, professional judgment was used to assign a single sensitivity rating to each asset if they were comparable with respect to the condition metrics or to rank one higher than another if the data demonstrated a clear difference and that indicated one was more sensitive than the other.

CITY OF ALAMEDA BRIDGES, BART AND RAILROAD STATIONS, BART AND RAIL LINES, SUPPORT FACILITIES AND BICYCLE/PEDESTRIAN ASSETS

Data availability for the assessment was limited for the City of Alameda bridges, Bay Area Rapid Transit (BART) and railroad stations, BART and rail lines, and support facilities and bicycle/pedestrian assets. Only a single sensitivity metric, liquefaction susceptibility, was consistently available to assign a rating. Due to this lack of data, the project team decided to remove sensitivity from the vulnerability equation for these assets and use only exposure and adaptive capacity to assign ratings. In some instances, this led to a mixed rating (e.g., HM) (see Section 5.2.5).

5.2.4 ADAPTIVE CAPACITY

The adaptive capacity of transportation assets includes the following:

- Potential for maintaining partial use while inundated (*note that this ultimately was not included in the vulnerability assessment*) and
- Adequate alternative route availability to maintain function while inundated.

It was considered that assets permanently exposed to inundation would be closed to further use but that partial use may be possible in cases where the inundation is temporary or associated with extraordinary events, such as a 100-year flood event. A roadway subject to 6 inches or less of inundation, for example, could still remain in operation, although its capacity may be reduced due to slower speeds. However, the inundation mapping exercise allowed the determination of inundation depths with certainty only to the nearest foot. Thus, the data could not assess the potential for maintaining partial use, as the level of inundation separating a facility that could remain in use and a facility that would have to be closed would differ by only a fraction of a foot.

The project team discovered a lack of guidance with respect to the effect of inundation exposure on the partial use or closure of transportation facilities. In Sausalito, the on-ramps to US 101 are currently subject to recurring flooding events, under which the ramps may be inundated under several inches of water. Despite this, the ramps remain open and traffic proceeds, albeit at slower speeds, as dictated by the situation. Caltrans was contacted regarding this situation, and it was related that there are no specific guidelines in place that would determine under how much inundation the ramps (or any other Caltrans facility) would be closed. This lack of guidance made it difficult to provide a complete assessment of adaptive capacity

The adaptive capacity of an asset was therefore determined solely by the availability of (a) comparable asset(s) that could provide an alternative route or provide a similar level of functionality should the asset be closed. This included considering transit as an alternative route should a roadway or bridge be closed. (It should be noted when developing potential adaptation strategies the adaptive capacity of assets can be more broadly defined as the ability to improve resilience to sea level rise through measures such as improved drainage or coastal protection etc.)

It should be highlighted that when evaluating adaptive capacity, the project team measured the inability to adapt for consistency of assigning a high, medium, or low rating relating to a high, medium or low vulnerability, so that a high rating always meant more vulnerable. Table 5.5 illustrates the rating approach, based on the identification of nearby or parallel assets that provide alternative routes or replacement functionality for each asset at midcentury. Alternative routes at end of century were assessed but not included in the Vulnerability rating, as the condition of the transportation network so far into the future was considered too speculative to include in the rating. (It is more standard practice to define adaptive capacity as the ability to adapt, which would lead to an asset that has a high adaptive capacity, having a high rating.)

Table 5.5 Adaptive Capacity

Climate Scenario	Inadequate Alternative Route (to Show Inability to Adapt)		
	High	Medium	Low
16” or 55” SLR + 100-year SWEL	No alternative route/ no comparable asset to replace functionality	An alternative route/ replacement asset is available but not fully comparable	Multiple alternative routes/comparable facilities available

In the case of linear assets (roadway segments, rail segments, and Bay Trail segments), both sides of the asset were considered to identify parallel routes that generally provide the same level of connectivity. If both “sides” provide an alternative, a low rating was given; if only one “side” offers an alternative route, a medium rating was assigned. In the case of “point” assets (bridges, rail stations, ferry terminals and facilities), the area around the asset was considered for nearby facilities that provide comparable functionality. A low rating was assigned if multiple alternatives were identified; if only one suitable alternative was located nearby, a medium rating was assigned. Thus, for example, while the BART line segments all received high ratings because there are not parallel alternative routes for BART trains, the Lake Merritt BART Station received a medium rating because if it were closed, BART passengers could still access the BART system at the nearby 12th Street Oakland City Center Station.

The ratings for the end-of-century scenario took an “if-then” approach, described as follows:

- If an asset received a high rating for the midcentury scenario, it automatically received a high rating for the end-of-century scenario (as greater inundation would not change the lack of an alternative route/replacement asset).

- If an asset received a medium rating for the midcentury scenario, and the alternative route/replacement asset would remain untouched by inundation during the 55-inch SLR plus 100-year flood event, then it also received a medium rating for the end-of-century scenario. If the alternative route/replacement asset identified would be touched by inundation during the 55-inch SLR plus 100-year flood event, then both the original asset and its replacement were considered to be similarly affected, and a high rating was given for the end-of-century scenario.

- If an asset received a low rating for the midcentury scenario, and a greater level of inundation under the 55-inch SLR plus 100-year flood event would not affect the identified alternative routes/replacement assets, then it also received a low rating for the end-of-century scenario. If the greater level of inundation at the end of the century would reduce the number of alternative routes/replacement assets to a single alternative, then a medium rating was assigned. If the level of inundation resulting from 55-inch SLR plus the 100-year flood would touch all of the identified alternative routes or replacement assets, then all were considered affected, similar to the original asset, and a high rating was given for the end-of-century scenario.

The vulnerability assessment incorporated only the ratings assigned for midcentury, although the ratings assigned for the end of the century were noted. The project team assumed that the transportation network may change considerably by the end of the century (due to adaptation strategies), so the ratings were not used to alter the vulnerability rating. Despite this uncertainty, the vulnerability ratings were not changed as a result of the rating assigned for the end of the century scenario.

5.2.5 OVERALL VULNERABILITY ASSESSMENT

As a result of the assessment exercise, each asset received a rating of high, medium, or low for each factor of exposure, sensitivity, and adaptive capacity (inability to adapt). Overall vulnerability was assigned according to the methodology outlined in Table 5.6. Some assets were not evaluated for sensitivity, in which case vulnerability was only based on exposure and the ability to re-route. The methodology for assigning vulnerability was revised during the process as described earlier in line with the data availability and in discussion with the Project Management Team (PMT).

Table C5.6 in Appendix C shows the list of assets and their respective vulnerability ratings (as well as which of those assets were selected to undergo the risk assessment process, and for which a risk profile was developed).

Table 5.6 Overall Vulnerability Assessment Method

Overall Vulnerability Score	Methodology
High (H)	Two or more highs
High/Medium (HM)	Where a sensitivity rating could not be assigned due to lack of data so only exposure and adaptive capacity ratings were included
Medium (M)	Two or more mediums or a combination of high, medium, and low.
Medium/Low (ML)	Where a sensitivity rating could not be assigned due to lack of data so only exposure and adaptive capacity ratings were included
Low (L)	Two or more lows

Table 5.7 illustrates the application of the vulnerability assessment methodology to four of the assets and the resultant ratings for exposure, sensitivity, inadequate adaptive capacity (mid century), and overall vulnerability.

Table 5.7 Vulnerability Assessment Method Applied to Select Assets

Code	Asset	Segments chosen	Exposure H/M/L	Sensitivity H/M/L	Inadequate adaptive capacity mid century H/M/L	Overall vulnerability rating H/M/L
R-01	I-80 (includes part of I-580)	Powell Street to Bay Bridge Toll Plaza	M	H	H	**H**
R-02a	I-880	Oak St to 23rd Ave	M	H	M	**M**
T -01	BART Transbay Tube		M	Lack of data	H	**HM**
T-04	Coliseum/ Airport BART Station	Access area and station	L	Lack of data	H	**M**

5.3 Risk Assessment

5.3.1 INTRODUCTION

The vulnerability assessment identified the vulnerability of the selected assets based on the information available. The next step in the process was to undertake a risk assessment of the most vulnerable assets to identify the level of risk from SLR facing the selected assets. A risk assessment typically looks at the likelihood that an asset would experience a particular impact (in this case, SLR) and the consequence of that impact on the surrounding community or region (as defined by the International Risk Assessment Standard, ISO31000:2009) It is most common to assess the risk of assets with medium- or high-level vulnerability, but for the purposes of the pilot project, a couple of representative assets rated as having low vulnerability were also moved forward to the risk assessment stage.

Generally, assets that have a low likelihood of being affected by future climate change (SLR) and a low consequence if that impact occurs are identified as having low risk, and those that have a high likelihood of being affected by future climate change and that would have a high consequence if that impact occurs are identified as having high risk. (It also allows for the differentiation between risks that have a high likelihood and low consequence, and a low likelihood and a high consequence.) Therefore, as a result of this analysis, agencies will have a risk profile associated with each of their representative assets to inform future adaptation strategies. High-risk assets will need to be prioritized for adaptation strategies, and low-risk assets will need to be monitored and revisited periodically to ensure that their risk status has not changed.

Risk Perception

Research indicates that one difficulty of conducting a risk assessment is the perception of risk: It is important to understand what it takes for people to be concerned enough to take mitigating action. A study by NOAA (2009), entitled *Risk Behavior and Risk Communication Synthesis*, focused on engaging the public in responding to immediate threats to coastal areas, such as evacuating before a hurricane. The study highlights risk (defined as Hazard x Exposure x Probability) as a social construct, noting that citizens' perceptions of risk are affected by the norms of the groups that they identify with. Risk perception is based on a wider framing on topics, considerations, and agendas. It reflects personal experiences and circumstances and is highly influenced by context, such as social networks. The following points summarize some key findings, which were appropriate for consideration in the risk assessment conducted by the project team:

- There is evidence that people who are asked to compare the level of risk between various alternatives perceive risk differently from that which actually exists. Risk has two dimensions: (1) what is known about the hazard itself and (2) what is felt about it, such as the level of dread or fear. The latter can have a large influence on the perception and assessment of risk.
- From a social and cultural perspective, emerging social norms can help engage others in perceiving and responding to risk, especially if the change agents are trusted community members. Also, top-down campaigns that use a heavy-handed approach to try to convince people that they or their property are at risk are not likely to succeed and may be resented. If engaged in the risk assessment process, citizens are more likely to accept the results and to perceive their risk adequately.
- There are barriers to communicating about risk, especially for long-term, less immediate risks, such as SLR. These barriers include other, and "bigger," more pressing problems and concerns for the stakeholders involved. Other risks, such as current financial issues, may be perceived as more important and requiring more immediate action.

For the vulnerability and risk assessment exercise of this pilot project those participating in the exercise included the organizations that made up the Transportation and Shoreline Sub Committees as described either in the report and the PMT. For these individuals, the hazard of SLR is a longer term threat to the communities and assets under their jurisdiction, but it is not a threat to their immediate livelihoods. Thus, it is expected that there are fewer emotional barriers to assessing risk/consequence of SLR. In addition, the development of guidance on how to address SLR (and legal requirements) provides the local agencies with tools to address the threat of SLR to their communities and assets, leaving the assessment of risk and development of a response less to the perception and will of individuals.

SELECTION OF ASSETS FOR RISK ASSESSMENT

As a result of the vulnerability assessment, the PMT selected the most vulnerable assets for the development of risk profiles, in order to develop two to three risk profiles per asset type. As part of this process, it was decided to combine some assets. The details of the vulnerability and consequence ratings for each of the selected assets can be found in their risk profiles (see Section 5.4).

In addition, a number of assets require special mention due to their unique circumstances, although they were not in the end selected to have a risk profile developed. The Lake Merritt BART station received a low vulnerability rating as it would not be inundated at midcentury or at the end of the century; however, it has current groundwater flooding issues that may be worsened through SLR. Future research is required to understand how this may affect its vulnerability. The Bay Trail is an asset that is highly vulnerable due to its location at the shoreline. However, it is not a typical transportation asset, so when compared to the other transportation assets, the impact of its inundation from a transportation perspective is low. The trail is nevertheless of great value to the region from a recreational perspective and provides a valuable commuting route for local populations.

Lake Merritt BART Station and BART Operations Control Center

The Lake Merritt BART Station is a transit facility serving Downtown Oakland and includes parking facilities. BART's Operations Control Center (OCC) adjoins the Lake Merritt Station, and functions as the nerve center of the 104-mile system, performing supervisory control of train operations and remote control of electrification, ventilation and emergency response systems. Due to lack of data, these assets were not rated with respect to sensitivity. The nearby 12th Street/Oakland City Center BART Station provides another option for accessing the BART system, offering adaptive capacity for the Lake Merritt BART Station, particularly if a "bus bridge" were established between these two locations. The Lake Merritt BART Station and OCC are not subject to inundation under either the 16" or 55" SLR scenarios, making exposure not applicable according to the approach used for the pilot project. However, the underground station and adjoining facilities are subject to groundwater infiltration, and water must be pumped out under present conditions. Though not exposed to inundation as the other assets considered, consequence can be assessed for Lake Merritt BART Station using the same methodology; as a sub-grade transit facility, consequence would be high for capital improvement costs and commuter use, moderate for time to rebuild, and low for goods movement. Additionally, the OCC is vital to the operation of the entire BART system, which has regional significance and importance for transit-dependent populations. Consequence would thus be high with regard to public safety and socioeconomic impact, making the Lake Merritt BART Station and OCC, considered together, a high-risk asset for purposes of comparison. Sea level rise may have an impact on groundwater levels and flows, potentially increasing their exposure on the station and the OCC. An analysis of these impacts is beyond the scope of this project but is recommended for future consideration.

Bay Trail and Connecting Trails

The Bay Trail provides easily accessible recreational opportunities for outdoor enthusiasts, including hikers, joggers, bicyclists and skaters. It also offers a setting for wildlife viewing and environmental education, and it increases public respect and appreciation for the Bay. It also has important transportation benefits, providing a commute alternative for cyclists, and connects to numerous public transportation facilities (including ferry terminals, light-rail lines, bus stops and Caltrain, Amtrak, and BART stations); also, the Bay Trail will eventually cross all the major toll bridges in the Bay Area. Within the subregion, the Bay Trail consists of off-street paved or gravel paths; on-street bike lanes and sidewalks; off-street unimproved paths (of varying width and surfaces). Other paved or gravel paths connect to the Bay Trail.

This project evaluated two off-street trail segments along the Alameda County shoreline: the trail around Lake Merritt connecting to the Bay Trail (the "Lake Merritt Connector Trail") and the segment of the Bay Trail along the Hayward Regional Shoreline (the "Hayward Regional Shoreline Trail"). Due to lack of data, these assets were not rated with respect to sensitivity. Exposure for both trail segments is high (due to significant inundation under both the 16" and 55" SLR scenarios). While the Lake Merritt Connector Trail has a parallel trail, it is likely to be similarly affected by inundation; no parallel trail is available for the Hayward Regional Shoreline Trail, making the vulnerability of both trail segments high. For both trail segments, all consequence criteria have a low rating, making them low-risk assets.

Bay Trail

Bay Trail

Lake Merritt Connector Trail

5.3.2 LIKELIHOOD

Likelihood is determined by estimating the probability that a certain climate change impact will occur. For this project, the climate change impact is limited to a certain set of SLR scenarios. Since this study considered only two climate change scenarios and the project area is relatively small, the likelihood rating is the same for each transportation asset for each scenario (Table 5.8). If a range of SLR scenarios had been considered (for example, different depths of inundation expected by midcentury), then a range of likelihoods could have been identified.

Table 5.8 Likelihood Rating

Scenario	Exposed to:	Remote (1)	Unlikely (2)	Likely (3)	Highly Likely (4)	Near Certainty (5)
Midcentury						
16” SLR + MHHW	High tide levels			X		
16” SLR + 100-year SWEL	100-yr SWEL			X		
End of Century						
55” SLR + MHHW	High tide levels			X		
55” SLR + 100-year SWEL	100-yr SWEL			X		

5.3.3 CONSEQUENCE

“Consequence” refers to the impact on the wider region of the inundation due to SLR. The Federal Highway Administration (FHWA) pilot model guidance suggests criteria to consider consequence, including the level of use of an asset, the degree of redundancy in the system, and the value of an asset to the surrounding community (e.g., goods movement, socioeconomic impacts, and/or decreased public safety). The criteria most relevant for the Alameda County context was identified, agreed with the PMT, and ranges of consequence or impact (major, moderate, and minor) were developed for direct and indirect impacts by the project team (Table 5.9). The consequence of an asset rendered unavailable to the community and region due to inundation was reviewed by applying this set of criteria to assess each vulnerable asset. Since consequence is considered on the basis of overall impacts on the community and region, ratings were assigned by comparing all asset types using the same rating scale. Where data did not exist, professional judgment was used to assign a rating to an asset across the consequence criteria. Appendix C discusses each of these professional judgments made by asset.

TRANSPORTATION AND SHORELINE ASSET SUBCOMMITTEES MEETING

In order to verify that the consequence or impact of inundation for the selected assets had been appropriately allocated, a joint meeting of the Transportation and Shoreline Asset Subcommittees was held. The main objective of the meeting was to elicit feedback on the consequence criteria definitions and the project team assessment of consequence ratings for each of the assets. The meeting also gave the project team an opportunity to update the subcommittees on overall progress to date. Very useful feedback was obtained, and a number of the criteria were refined as a result, including the definitions of the public safety and the socioeconomic criteria, changing the impact ranking for some of the assets.

OVERALL CONSEQUENCE RATING

The project team averaged the six consequence criteria ratings for each asset to provide a final numerical rating. Although up to two significant figures were initially recorded for the consequence rating to show variation between assets, the ratings were rounded up or down for use for the overall final risk assessment (Figure 5.2). Note that averaging the consequence rating may mask the highest consequence rating so that agencies may wish in future to add a weighting to impacts that they feel are more important than others. Table 5.10 gives an example of the rating assigned for the Webster Tube.

Table 5.9 Consequence Criteria

	Major Consequence Rank 5	Moderate Consequence Rank 3	Minor Consequence Rank 1	Source of Information
Direct Asset Impact				
Capital improvement cost (original cost in 2011 $) Cost to restore to same design standard/ infrastructure type	$$$$ More than $50 million	$$$ $20–50 million	$$ Less than $20 million	Agencies (e.g., Caltrans, BART, MTC), professional judgment
Time to rebuild when damaged beyond further use (if rebuilding is possible)	Length of time - long Greater than 5 years	Length of time - medium 2–5 years	Length of time – short 2 years or less	Agencies (e.g., Caltrans, BART, MTC), professional judgment
Indirect Asset Impact – Community/Regional Socioeconomic Function Impacts				
Public safety: lifeline/evacuation route impact	Lifeline highway routes affected (Bay Bridge; I-80 from the Bay Bridge Toll Plaza to the project boundary)	Evacuation routes (as defined by cities) affected	Little expected impact on functionality of known lifeline/ evacuation routes	Caltrans, cities
Economic Impact (goods movement)	Major goods traffic affected More than 5,000 annual average daily truck trips (AADTT)	Some goods traffic affected Fewer than 5,000 AADTT	Minor goods traffic affected AADTT not applicable	Agencies (e.g., Caltrans, MTC), professional judgment
Economic Impact (commuter route) Ridership/train load for transit (ridership numbers are bi-directional)	Affects medium-high-volume commuter route More than 10,000 daily riders or freeway	Affects medium-volume commuter route. 10,000 or fewer daily riders	Affects low-volume commuter route Assets that are not used by transit vehicles	Agencies (e.g., BART, AC Transit)
Socioeconomic impact (transit-dependent population/ MTC communities of concern)	Asset is located in an MTC community of concern and/or in an area with low car ownership and provides access to multiple transit lines	Asset facilitates “pass through” traffic of multiple transit lines or is located in an MTC community of concern and/or in an area with low car ownership and provides access to just one transit line	Asset not located in area of MTC communities of concern or area with low car ownership, or does not facilitate transit	MTC
Recreational impact *[Note: Not included in rating;]**	Permanent loss of some recreational access infrastructure/ shoreline access/ connectivity	Partial loss of recreational access infrastructure/ shoreline access/ connectivity	No interruption of recreational access infrastructure/ shoreline access/ connectivity	Not yet assessed

*Note that although recreational impact was considered, it was eventually removed from the risk profile template when it was decided to remove the Bay Trail from inclusion. This criterion had been included originally to highlight the unique benefits that the Bay Trail provides the region.

Table 5.10 Example Consequence Rating

Asset R-11: Webster Tube (SR 61) including approach ramps	Major Consequence 5	Moderate Consequence 3	Minor Consequence 1
Capital Improvement Cost (Original cost in 2011 $)	Replacement cost: $180,000,000		
Time to rebuild when damaged beyond further use	Seismic retrofit took about 8 years; rebuild would take at least as long		
Public safety: Lifeline/Mass evacuation route impact		Alameda evacuation route	
Economic Impact (Goods movement)		535 AADTT	
Economic Impact (Commuter route)	18,333 daily riders		
Socioeconomic impact		MTC communities of concern and pass-through transit (multiple lines)	
Total Average	4.0		

The risk profiles in Appendix C show the detail of the consequence ratings for each asset.

OVERALL RISK RATING

The project team used a matrix provided by the FHWA conceptual model that evaluates both likelihood and consequence (Figure 5.2) to allocate an overall risk profile for each asset. In this project, due to the unique definition of "likelihood," each asset received a score of 3 for likelihood and a score of from 1 to 5 for consequence, which, when added together, yields an overall score that is categorized as high, moderate, or low risk. The following examples provide more detail on the approach used:

- An asset with a likelihood rating of 3, with an overall consequence impact rating of 1 would result in an overall risk assessment of 4 (low).
- An asset with a likelihood rating of 3, with an overall consequence impact rating of 3 would result in an overall risk assessment of 6 (moderate).
- An asset with a likelihood rating of 3, with an overall consequence impact rating of 5 would result in an overall risk assessment of 8 (high).

5.4 Risk Profiles

5.4.1 INTRODUCTION

A risk profile summarizes the vulnerability and risk characteristics identified for each of the selected assets. Its purpose is to act as an information source and tool for the development and prioritization of adaptation strategies for the agencies responsible for each asset. In addition to the vulnerability and risk characteristics, each of the risk profiles contains data relating to the overtopping potential described in Section 4.3.2. Table 5.11 details the final list of risk profiles developed. Figure 5.3 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.) Appendix C presents the risk profiles for the selected assets.

	Consequence					
Likelihood		1	2	3	4	5
	1	2	3	4	5	6
	2	3	4	5	6	7
	3	4	5	6	7	8
	4	5	6	7	8	9
	5	6	7	8	9	10
Risk	Low		Moderate		High	

High Risk (Red)

Unacceptable, major disruption likely; priority management attention required.

Moderate Risk (Orange)

Some disruption; additional management attention may be needed.

Low Risk (Green)

Minimum impact; minimum oversight needed to ensure risk remains low.

Figure 5.2 Risk Rating Matrix

Table 5.11 Final List of Risk Profiles, by Asset Category and Asset Type, Showing Final Risk Rating

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

Code	Asset Category and Asset Types	Segments Chosen	Final Risk Rating
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
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

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 5.3 Risk Profile Glossary: Asset Name (Asset Code)

5.5 Recommended Refinements to the FHWA Conceptual Model

5.5.1 LESSONS LEARNED

DATA COLLECTION

As mentioned in Chapter 2, due to the large number of important transportation assets in the project area, extensive data collection requests related to specific transportation assets were delayed until the asset list had been shortened so that agencies were not overwhelmed by the data requests. This included the information required to assess the condition of the asset to inform the sensitivity component of the vulnerability analysis (such as its age, whether or not it had been seismically retrofitted, its annual O&M budget) and the potential impact of inundation to inform the consequence component of the analysis (such as cost and time to rebuild). Data were sometimes also received after deadlines set by the project team, which led to the need for repeated updates to the inventory and to both the vulnerability and risk assessment exercises. The amount of effort and time required to collect data should not be underestimated.

DEFINITIONS

The methodology used for the vulnerability assessment was a truly iterative process, due to the number of approaches to vulnerability assessment and the number of interpretations of some of the key terms (even between different papers produced by the Intergovernmental Panel on Climate Change). For example, some approaches consider adaptive capacity as part of the vulnerability equation, and some do not, assuming that this could mask the true vulnerability of an asset. The project team had extensive discussions to work out what the most appropriate approach was for the project area and assets, bearing in mind the information available. For example, the team originally considered both the potential for maintaining partial use of an asset while it was inundated and the availability of an adequate alternative route to maintain function while the asset is inundated as important components of adaptive capacity of a transportation asset. But this was revised to just refer to the availability of an adequate alternative route. Initially, the project team considered that adaptive capacity should be considered as part of the consequence of inundation (if the asset has adaptive capacity, it is of lower consequence to the region) but finally concluded that as long as low-cost adaptive capacity measures only were considered, it should be part of the vulnerability equation.

INTEGRATION OF SHORELINE ASSETS INTO THE ASSESSMENT

If and how the performance of the shoreline assets should feed into a vulnerability assessment was also a topic of much discussion. Using the inundation mapping information generated for the project, it is possible to look in detail at which shoreline assets were overtopped where and to what depth, providing useful information for future adaptation strategies. It was decided, however, that there was not sufficient information available regarding the likely future maintenance, and upgrade schedule for the shoreline assets to understand with confidence how the overtopping potential may affect the vulnerability of the assets. It was decided in the end that this information would be best utilized as a tool to help figure out the most appropriate adaptation strategies to protect the transportation asset. Knowing how much and to what depth the closest shoreline protection system was overtopped would allow both the prioritization and the development of the most appropriate adaptation strategies. This is an indication of the adaptive capacity of the shoreline assets.

TREATMENT OF DIFFERENT ASSET TYPES

At different points in the process, assets were compared within or across asset types. When sensitivity data were reviewed, in order to develop sensible ranges of low, medium, and high, assets were compared within ranges (e.g., in terms of cost, replacement time). When reviewing consequence impact data, assets were compared across asset types to ensure comparison of truly comparable assets and to assist in appropriate prioritization.

There was much discussion regarding how to assess the Bay Trail and other pedestrian or bicycle infrastructure in terms of impact or consequence of inundation from SLR. Although the Bay Trail is of great importance as a recreational and social asset for the local community and is a valuable commuting route for some, when compared to other transportation infrastructure, such as freeways or the Bay Tube, it cannot compete in terms of regional transportation significance. For the risk assessment exercise for this project as described above, all assets were compared using a common scale in order to use the assessment as a prioritization tool. The Bay Trail was carried through the vulnerability assessment stage as an important representative asset for the region and was determined to be highly vulnerable. However, when assessed with the consequence criteria, it was determined to have low impact or consequence (because it would be comparatively inexpensive to rebuild and does not carry significant commuter or goods traffic) relative to other assets. Given the trail's importance to the region (even though not from a regional transportation perspective), the project team decided that it was not appropriate to label it of low consequence if it were inundated. (It should be noted that for other projects, if prioritization or comparison is not made across asset types, then metrics can be developed to enable assets to be compared within their asset types.)

5.5.2 RECOMMENDATIONS FOR FUTURE APPLICATIONS

Recommendations for the vulnerability and risk component of the process include the following:

- Provide fuller definitions or guidance on what exposure, sensitivity, and adaptive capacity mean and how to use them for different project types.
- Obtain early input from stakeholders on definitions of the consequence impact criteria as this insight is valuable to ensuring that criteria are tailored to the local context. For example, during the project, the definition used for "public safety" was expanded from a defined California Department of Transportation lifeline route to include routes that were identified as emergency evacuation routes by local cities.
- Provide guidance about whether or not agencies may wish to add a weighting to certain impacts in the instance that multiple impacts are being rated and averaged to provide an overall consequence rating which may mask the highest (and most concerning) consequence rating
- Organizational impacts to the agencies themselves are not included as consequence criteria and should be considered in the future. Decisions made by agencies today that increase the vulnerability by not taking climate change into account may led to liability issues in the future.
- Provide guidance and examples on how to rate the sensitivity of an asset when the availability of data is inconsistent between assets.
- Provide guidance on how to include consideration of the impact of potentially accelerated asset deterioration due to e.g. temporary inundation during storm events

- Provide guidance and examples on the methodology developing the ranges (major – moderate – minor) for rating assets against different consequence criteria, particularly when qualitative data may be hard to obtain, yet participants are not comfortable using professional judgment to rate an impact.
- Ensure that asset types only of comparable scale/class are included in the same assessment.
- Provide guidance on when it is appropriate to assess assets across asset types and when it is appropriate to assess assets within asset types.
- Provide guidance on the range of asset types that should be included in a project scope so that like-with-like comparisons can be made.
- Agencies should put in place data inventory development processes to consolidate data about transportation assets to facilitate future risk assessment exercises.
- Include guidance or suggestions on what type of more detailed inundation mapping can be helpful for prioritizing vulnerable assets and understanding how the protection that a shoreline asset is offering changes with SLR.
- If more detailed inundation mapping is done for projects looking at SLR in particular, ensure that time is factored into the schedule to account for this.

5.6 References

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Sea Level Rise Maps 6.0

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6 Sea Level Rise Maps

6.1 Introduction

This chapter contains the maps generated for the Federal Highways Administration (FHWA) pilot project (as listed in Table 6.1). There are two main types of maps – those that show expected inundation, and those that show the overtopping potential of the shoreline assets. The inundation maps present the depth and extent of inundation associated with the six inundation scenarios evaluated as part of this effort. Each SLR scenario -16 inches (40 cm) by mid-century and 55 inches (140 cm) by end of 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 still water elevations (100-yr SWEL), and inundation associated with 100-year extreme water levels coupled with wind waves (100-yr SWEL + wind waves). The depth of inundation information associated with the six inundation scenarios was extracted along the shoreline assets to provide a high-level assessment of the potential for shoreline overtopping. The shoreline overtopping potential maps present the results of this exercise. Please refer to Section 4.2 for details on what the inundation and overtopping maps show.

Before reviewing the maps, please read Section 6.2 to understand the caveats associated with the maps due to data availability and methodology limitations.

Table 6.1 Number of maps produced by type

	Inundation overview	Inundation zoom-in maps	Overtopping depth	Overtopping %	Overtopping depth zoom-ins
16" + MHHW	1	5	1	1	0
16" + 100-yr SWEL	1	5	1	1	5
16" + 100-yr SWEL + wind waves	1	5	1	1	0
55" + MHHW	1	5	1	1	0
55" + 100-yr SWEL	1	5	1	1	5
55" + 100-yr SWEL + wind waves	1	5	1	1	0
Total	**6**	**30**	**6**	**6**	**10**

6.2 Caveats Associated with the Maps

The inundation maps and shoreline overtopping potential maps are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and the maps do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context on the maps and analyses, including a description of the data and methods used, please refer to Chapter 4 and the associated Appendix. Users agree to hold harmless and blameless the State of California and its representatives and its agents for any liability associated with the use of the maps. The maps and data shall not be used to assess actual coastal hazards, insurance requirements, or property values or be used in lieu of Flood Insurance Rate Maps issued by the Federal Emergency Management Agency (FEMA).

The inundation maps created for the pilot study region represent advancement over previous inundation maps that characterized the extent of inland inundation due to sea level rise. Most notably, the new maps include:

- The depth and extent of inundation.
- The maps rely on topographic information from the 2010 USGS LIDAR. 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 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 intended only 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 the following 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 impact flood water conveyance are derived from the USGS 2010 LIDAR at a two meter horizontal grid resolution. Although this data set represents the best available topographic data, and the data has undergone a rigorous QA/QC by a third party, the data has not been extensively ground-truthed. Levee crests and other topographic features may be over or under-represented 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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INUNDATION OVERVIEW MAPS

16" MHHW (1)

16" MHHW + 100-yr SWEL (1)

16" MHHW + 100-yr SWEL + wind waves (1)

55" MHHW (1)

55" MHHW + 100-yr SWEL (1)

55" MHHW + 100-yr SWEL + wind waves (1)

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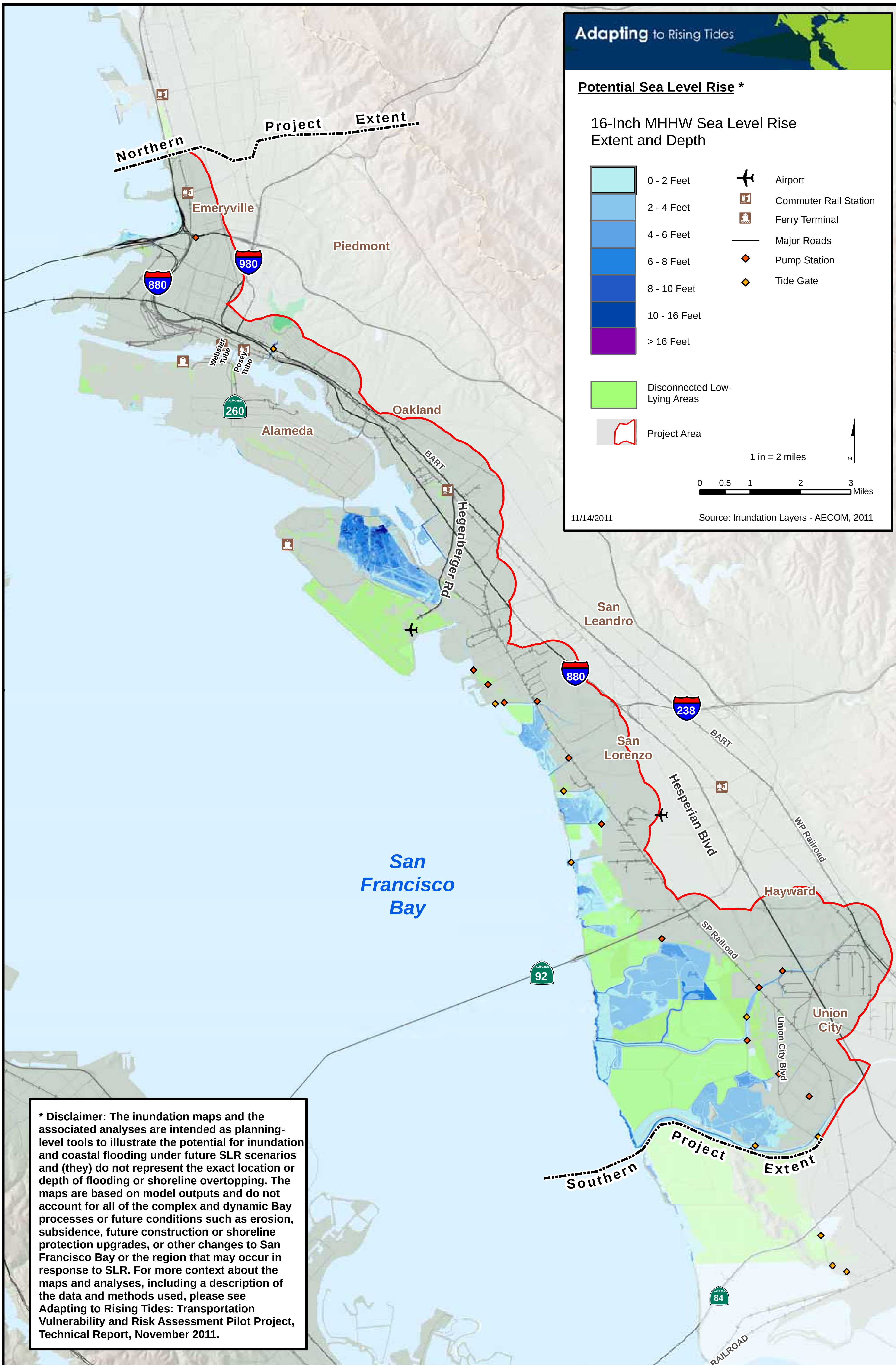
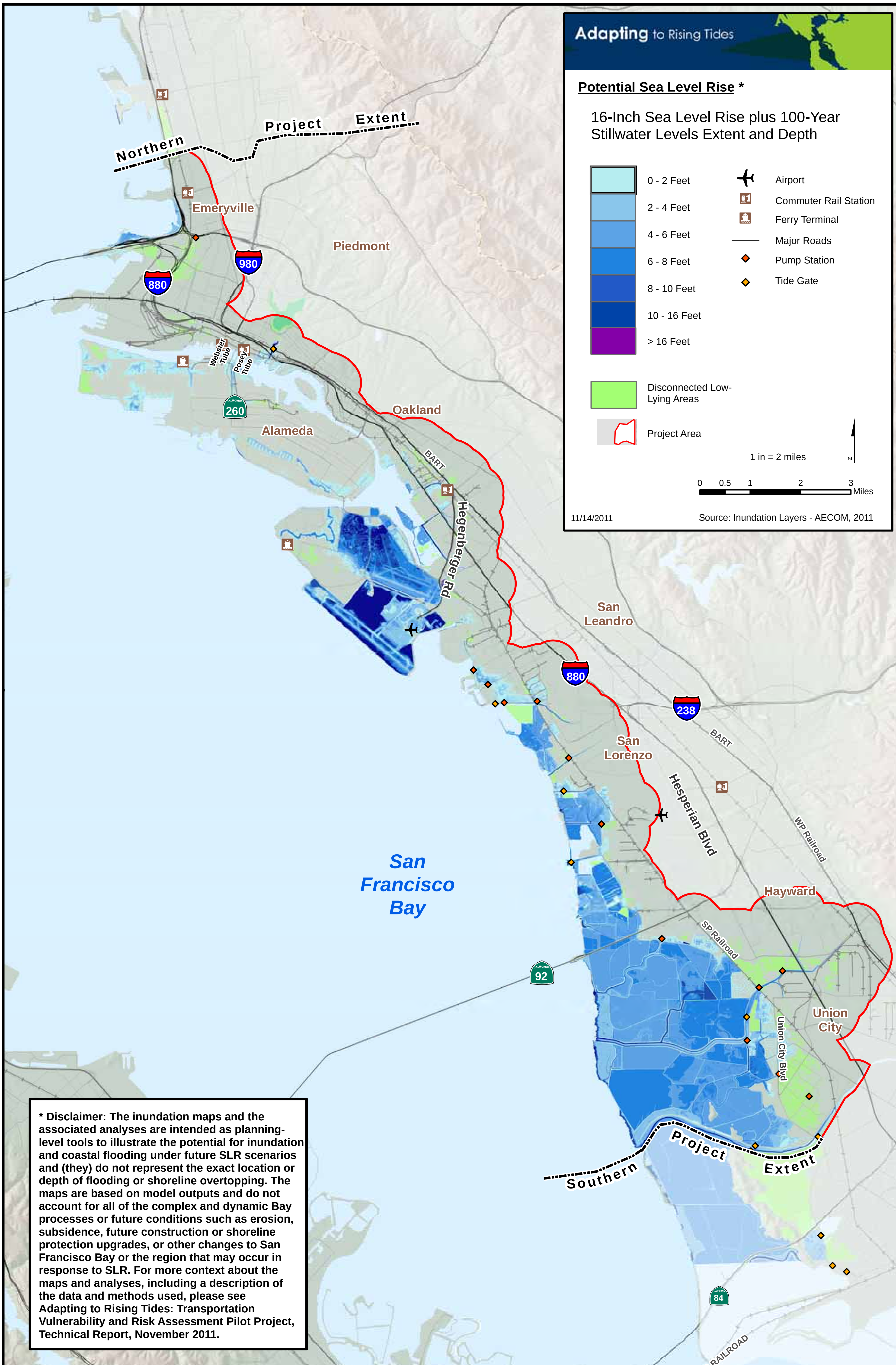


* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.



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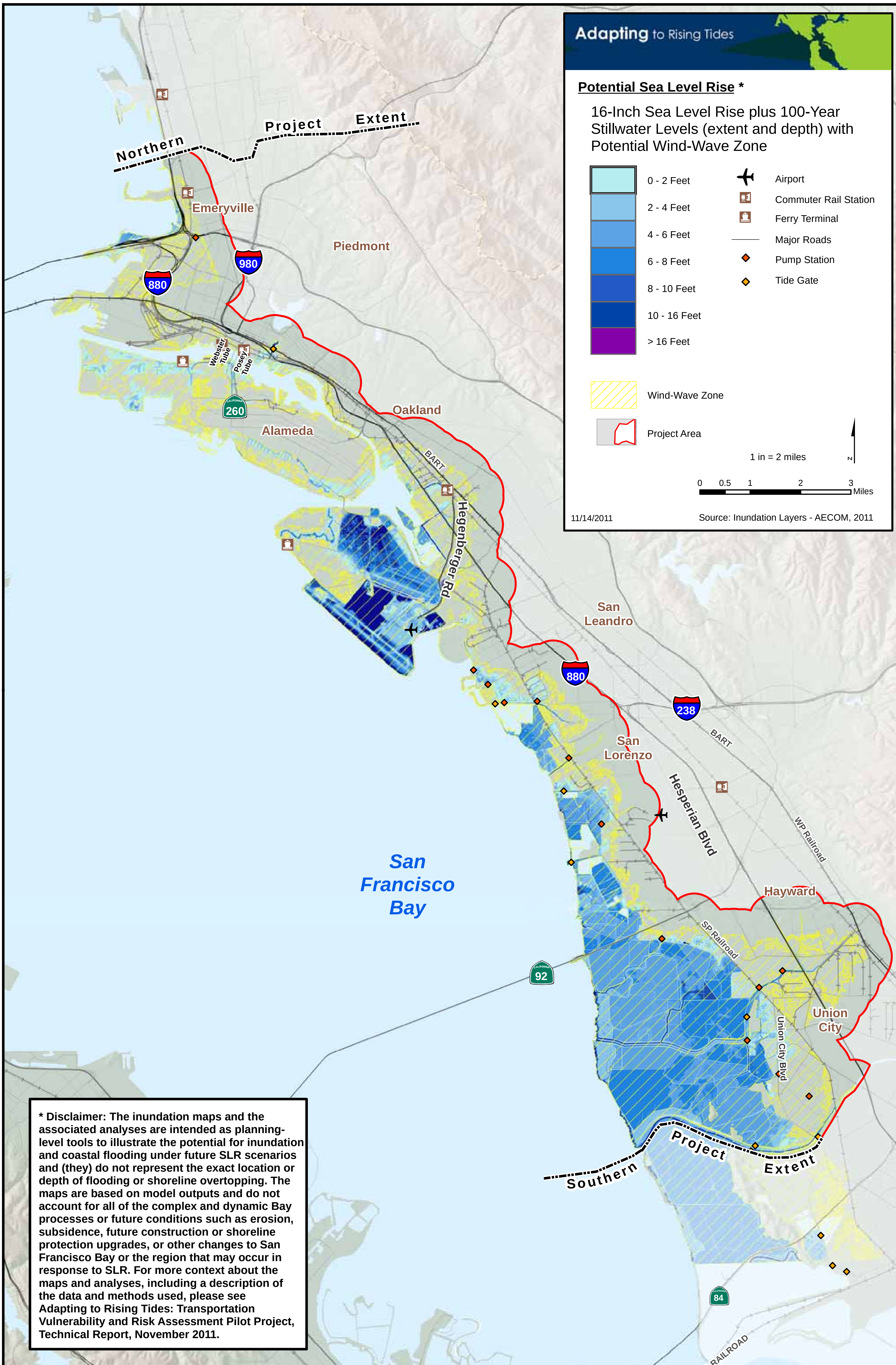
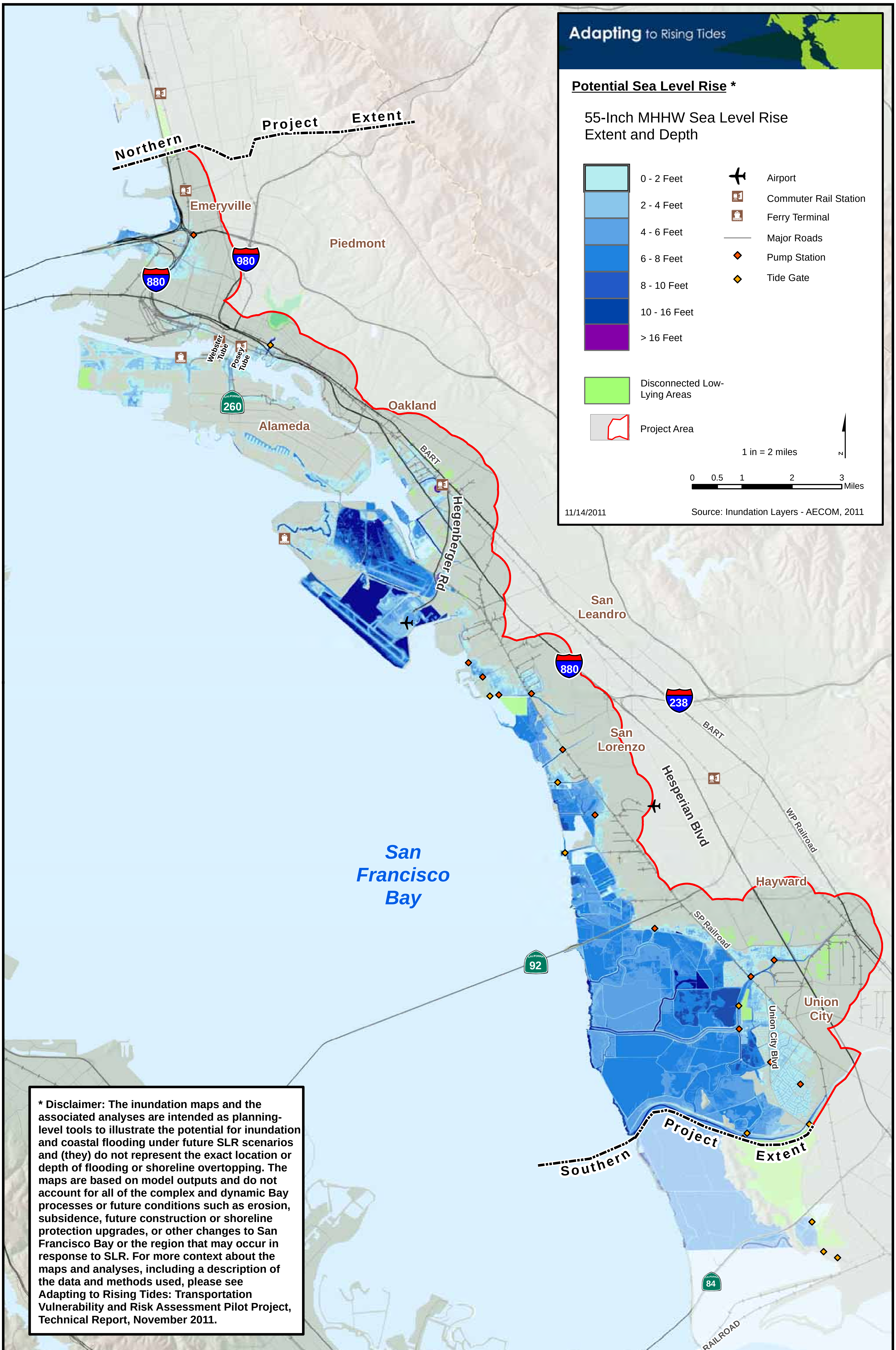


* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.



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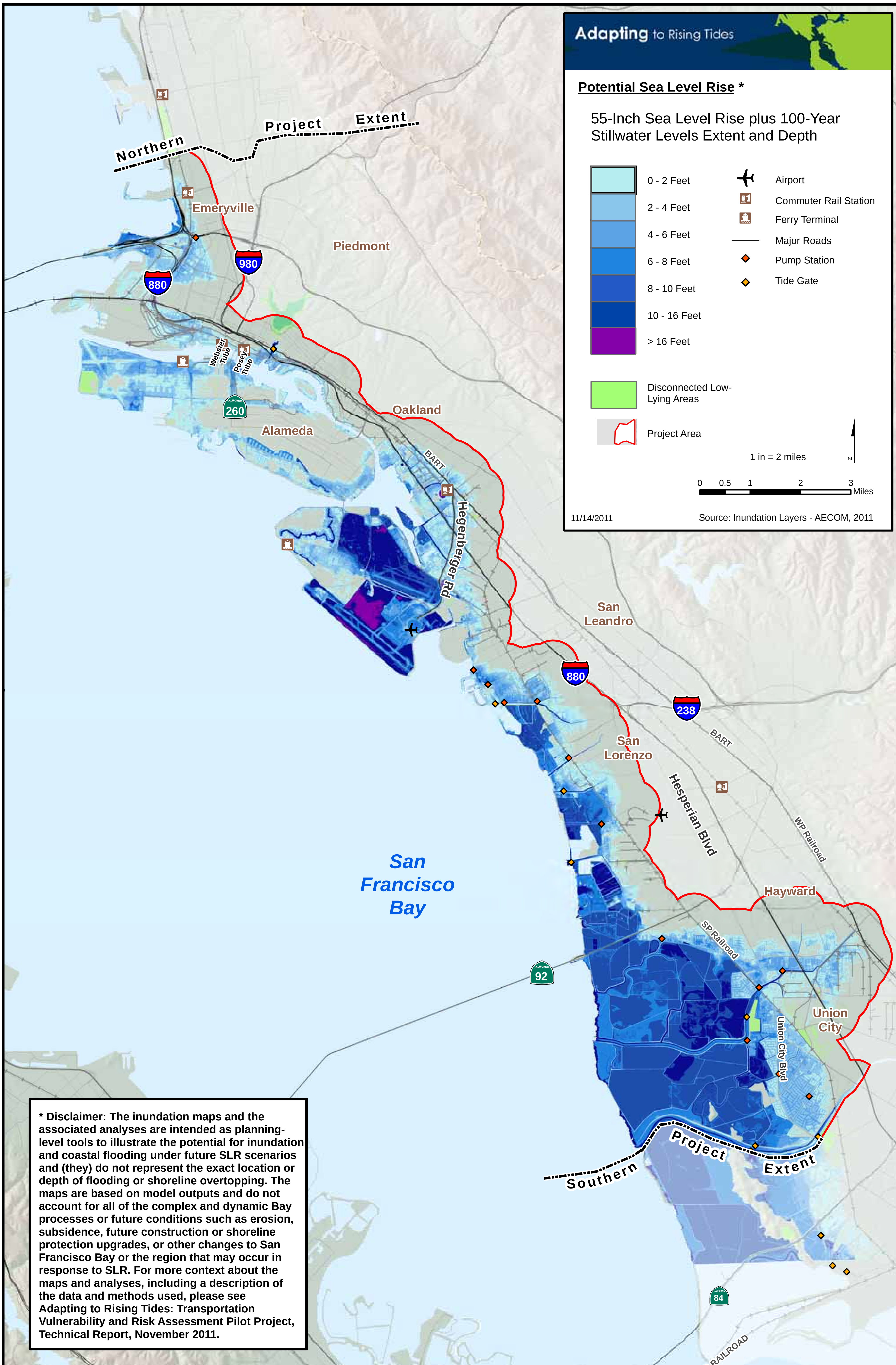
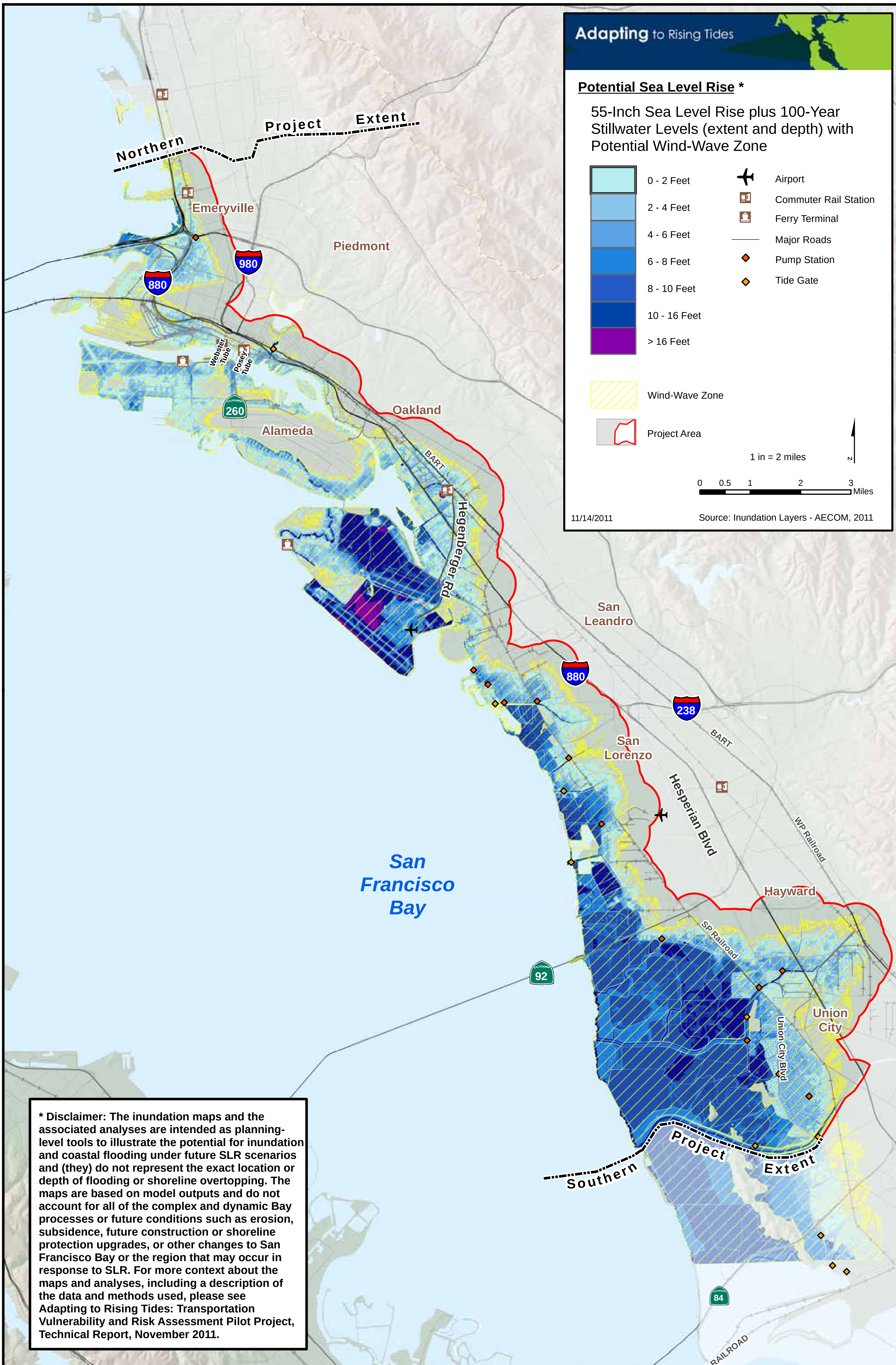


* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.



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INUNDATION ZOOM-IN MAPS SHOWING SELECTED TRANSPORTATION ASSET LOCATION

16" MHHW (5)

16" MHHW + 100-yr SWEL (5)

16" MHHW + 100-yr SWEL + wind waves (5)

55" MHHW (5)

55" MHHW + 100-yr SWEL (5)

55" MHHW + 100-yr SWEL + wind waves (5)

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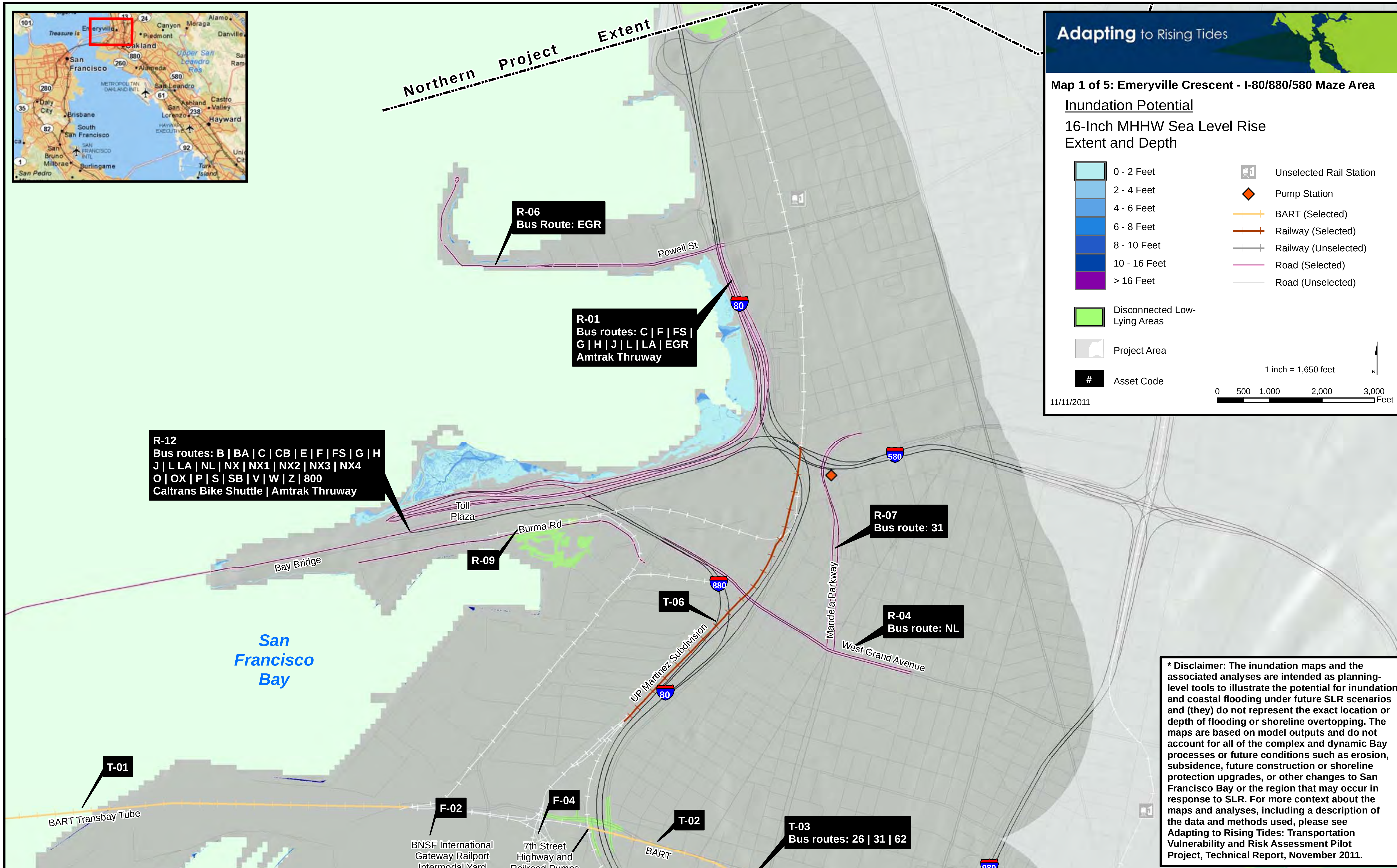
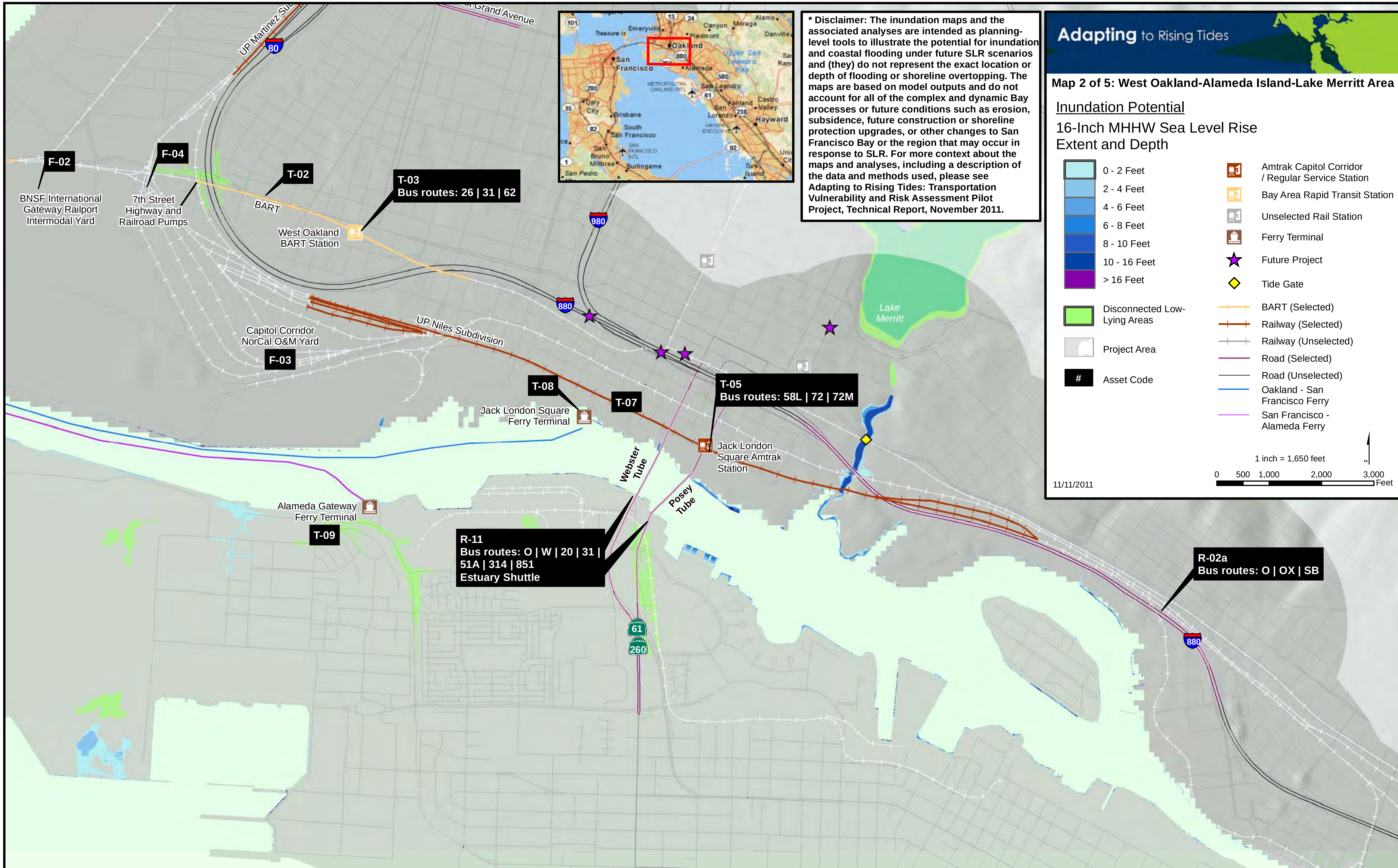
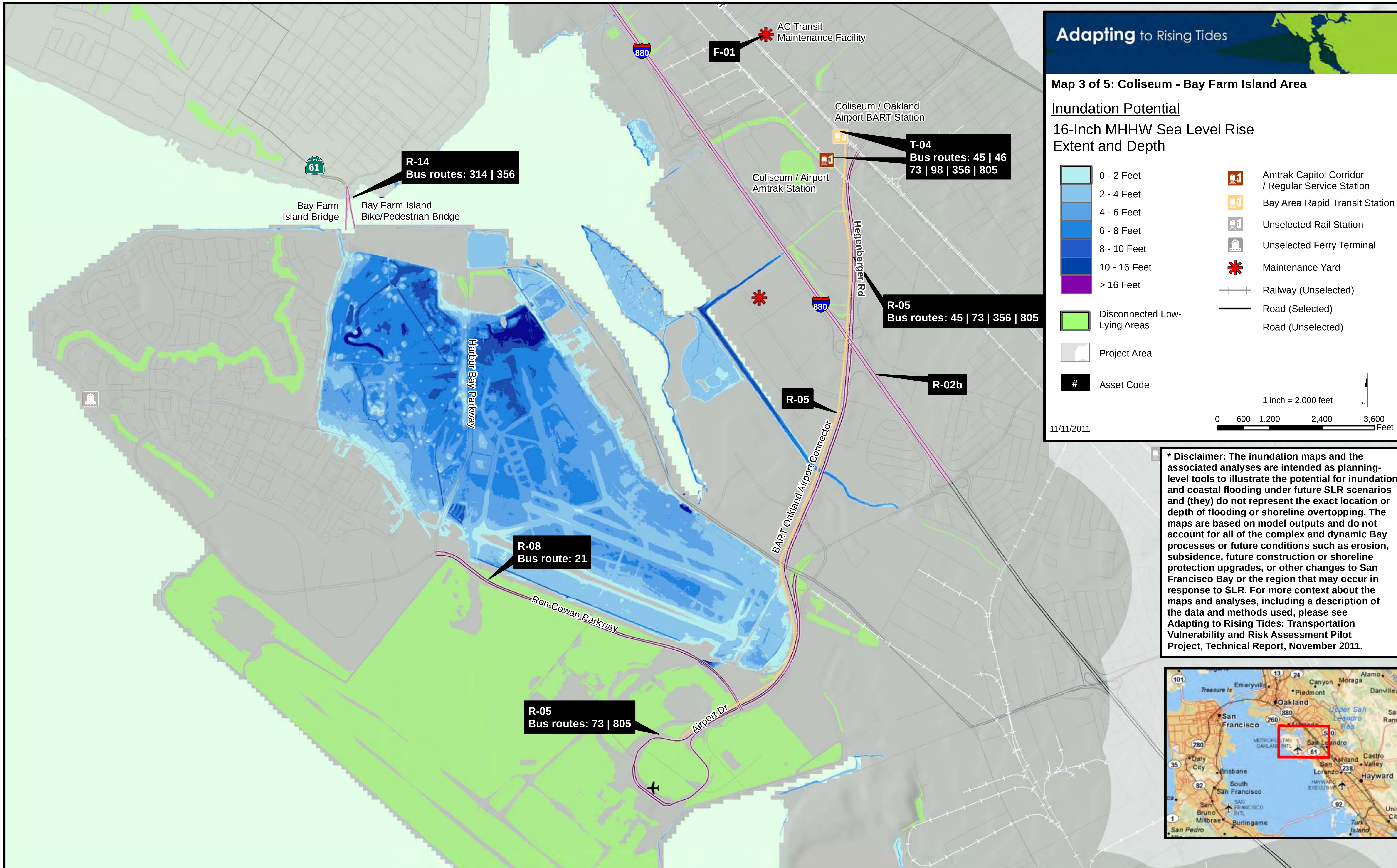
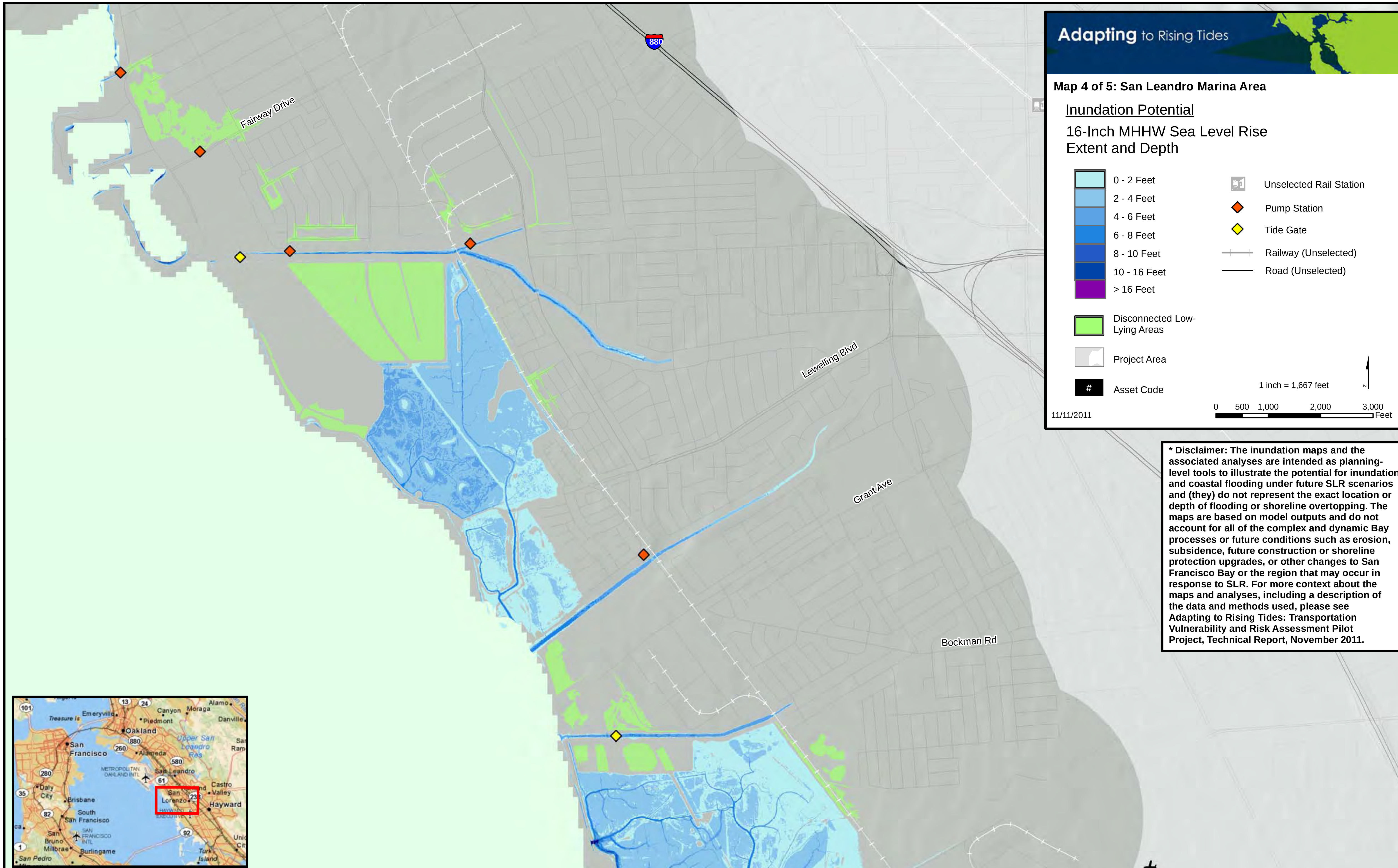

Adapting to Rising Tides
Map 1 of 5: Emeryville Crescent - I-80/880/580 Maze Area
Inundation Potential
16-Inch MHHW Sea Level Rise
Extent and Depth
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Disconnected Low-Lying Areas
Project Area
Asset Code
Unselected Rail Station
Pump Station
BART (Selected)
Railway (Selected)
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 1,650 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
Northern Project Extent
R-06
Bus Route: EGR
Powell St
R-01
Bus routes: C | F | FS | G | H | J | L | LA | EGR
Amtrak Thruway
R-12
Bus routes: 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
Toll Plaza
Burma Rd
Bay Bridge
R-09
R-07
Bus route: 31
580
80
880
T-06
Mandela Parkway
R-04
Bus route: NL
West Grand Avenue
UP Martinez Subdivision
San Francisco Bay
T-01
BART Transbay Tube
F-02
BNSF International Gateway Railport Intermodal Yard
F-04
7th Street Highway and Railroad Pumps
T-02
BART
T-03
Bus routes: 26 | 31 | 62
980
Emeryville
Oakland
San Francisco
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.


Adapting to Rising Tides
Map 2 of 5: West Oakland-Alameda Island-Lake Merritt Area
Inundation Potential
16-Inch MHHW Sea Level Rise Extent and Depth
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Disconnected Low-Lying Areas
Project Area
Asset Code
Amtrak Capitol Corridor / Regular Service Station
Bay Area Rapid Transit Station
Unselected Rail Station
Ferry Terminal
Future Project
Tide Gate
BART (Selected)
Railway (Selected)
Railway (Unselected)
Road (Selected)
Road (Unselected)
Oakland - San Francisco Ferry
San Francisco - Alameda Ferry
1 inch = 1,650 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
F-02
BNSF International Gateway Railport Intermodal Yard
F-04
7th Street Highway and Railroad Pumps
T-02
BART
T-03
Bus routes: 26 | 31 | 62
West Oakland BART Station
UP Martinez Sub
Grand Avenue
Capitol Corridor NorCal O&M Yard
F-03
UP Niles Subdivision
T-08
Jack London Square Ferry Terminal
T-07
T-05
Bus routes: 58L | 72 | 72M
Jack London Square Amtrak Station
Lake Merritt
Webster Tube
Posey Tube
Alameda Gateway Ferry Terminal
T-09
R-11
Bus routes: O | W | 20 | 31 | 51A | 314 | 851
Estuary Shuttle
R-02a
Bus routes: O | OX | SB
80
980
880
61
260
San Francisco
Oakland
Alameda
Emeryville
Piedmont
Daly City
Brisbane
South San Francisco
San Leandro
Hayward
Castro Valley
San Bruno
Millbrae
Burlingame
San Pedro
Alamo
Moraga
Canyon
Danville
Lorenzo
Ashland
Upper San Leandro Res
Metropolitan Oakland Intl
San Francisco Intl
Hayward Executive


Adapting to Rising Tides
Map 3 of 5: Coliseum - Bay Farm Island Area
Inundation Potential
16-Inch MHHW Sea Level Rise
Extent and Depth
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Disconnected Low-Lying Areas
Project Area
Asset Code
Amtrak Capitol Corridor / Regular Service Station
Bay Area Rapid Transit Station
Unselected Rail Station
Unselected Ferry Terminal
Maintenance Yard
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 2,000 feet
0 600 1,200 2,400 3,600 Feet
11/11/2011
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
AC Transit Maintenance Facility
F-01
880
Coliseum / Oakland Airport BART Station
T-04
Bus routes: 45 | 46 73 | 98 | 356 | 805
Coliseum / Airport Amtrak Station
R-14
Bus routes: 314 | 356
61
Bay Farm Island Bridge
Bay Farm Island Bike/Pedestrian Bridge
Hegenberger Rd
R-05
Bus routes: 45 | 73 | 356 | 805
R-02b
R-05
Harbor Bay Parkway
BART Oakland Airport Connector
R-08
Bus route: 21
Ron Cowan Parkway
R-05
Bus routes: 73 | 805
Airport Dr
Oakland
San Francisco
Treasure Is
Emeryville
Piedmont
Canyon
Moraga
Alamo
Danville
San Leandro
San Lorenzo
Ashland
Castro Valley
Hayward
Daly City
Brisbane
South San Francisco
San Bruno
Millbrae
Burlingame
San Pedro



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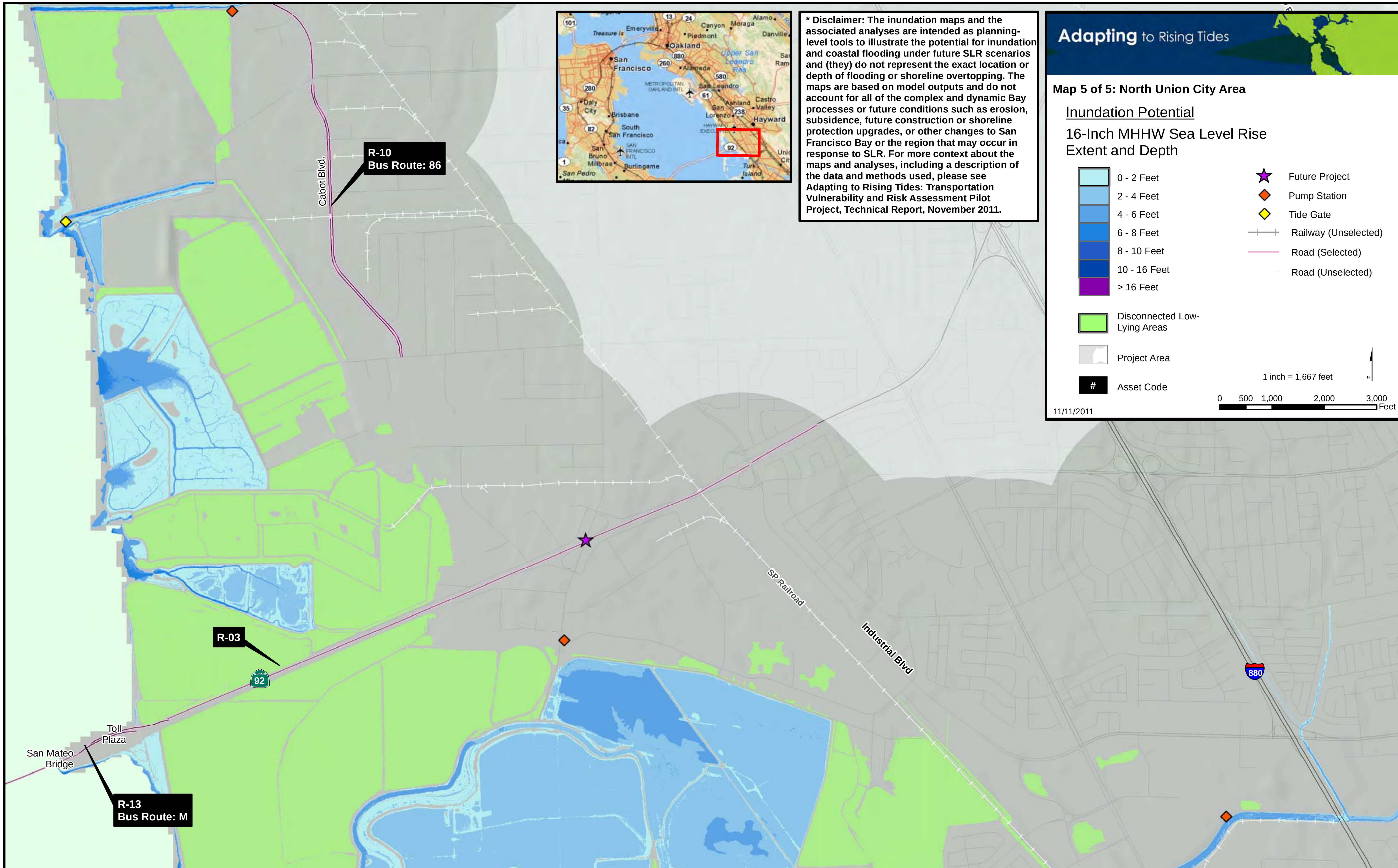
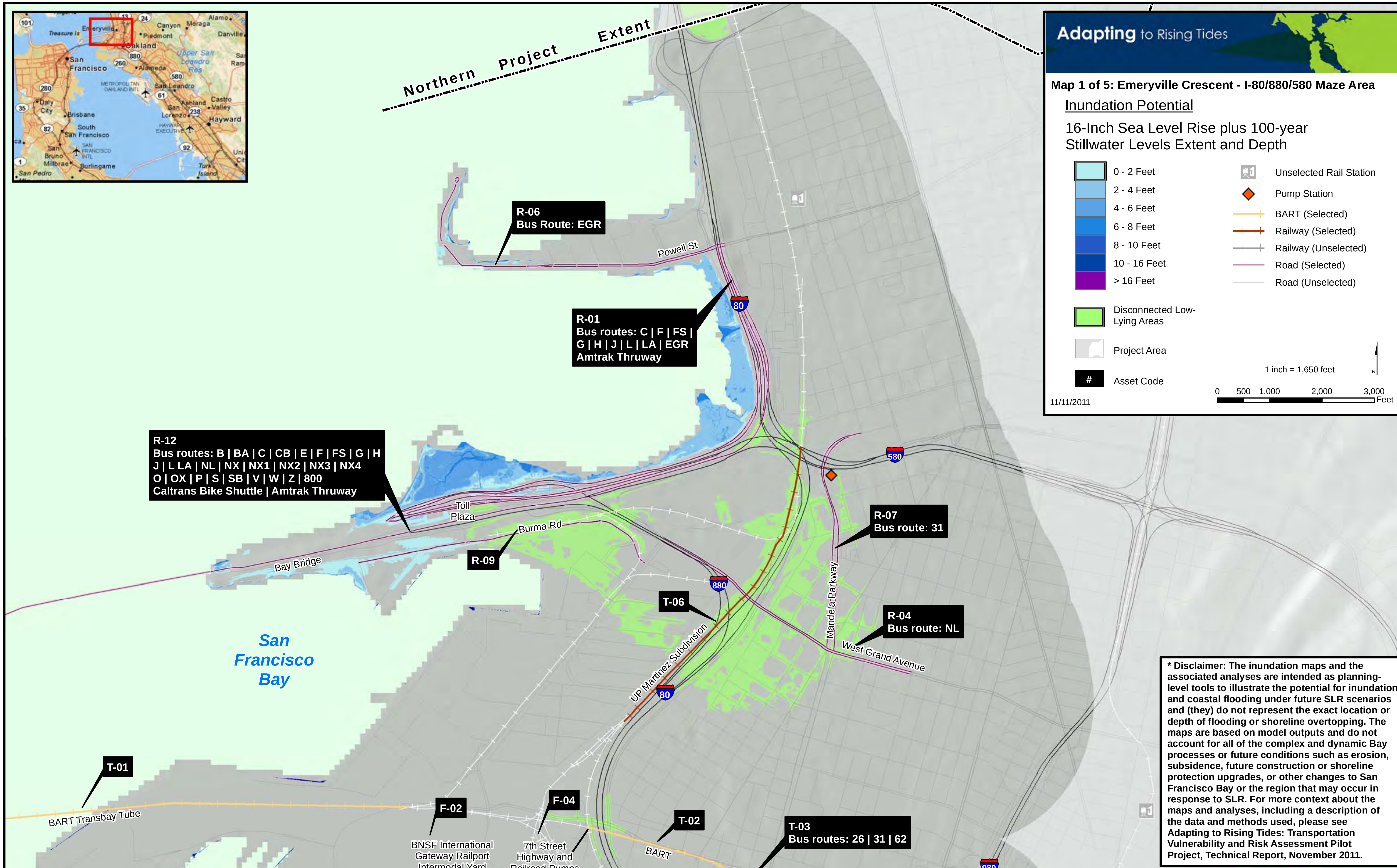
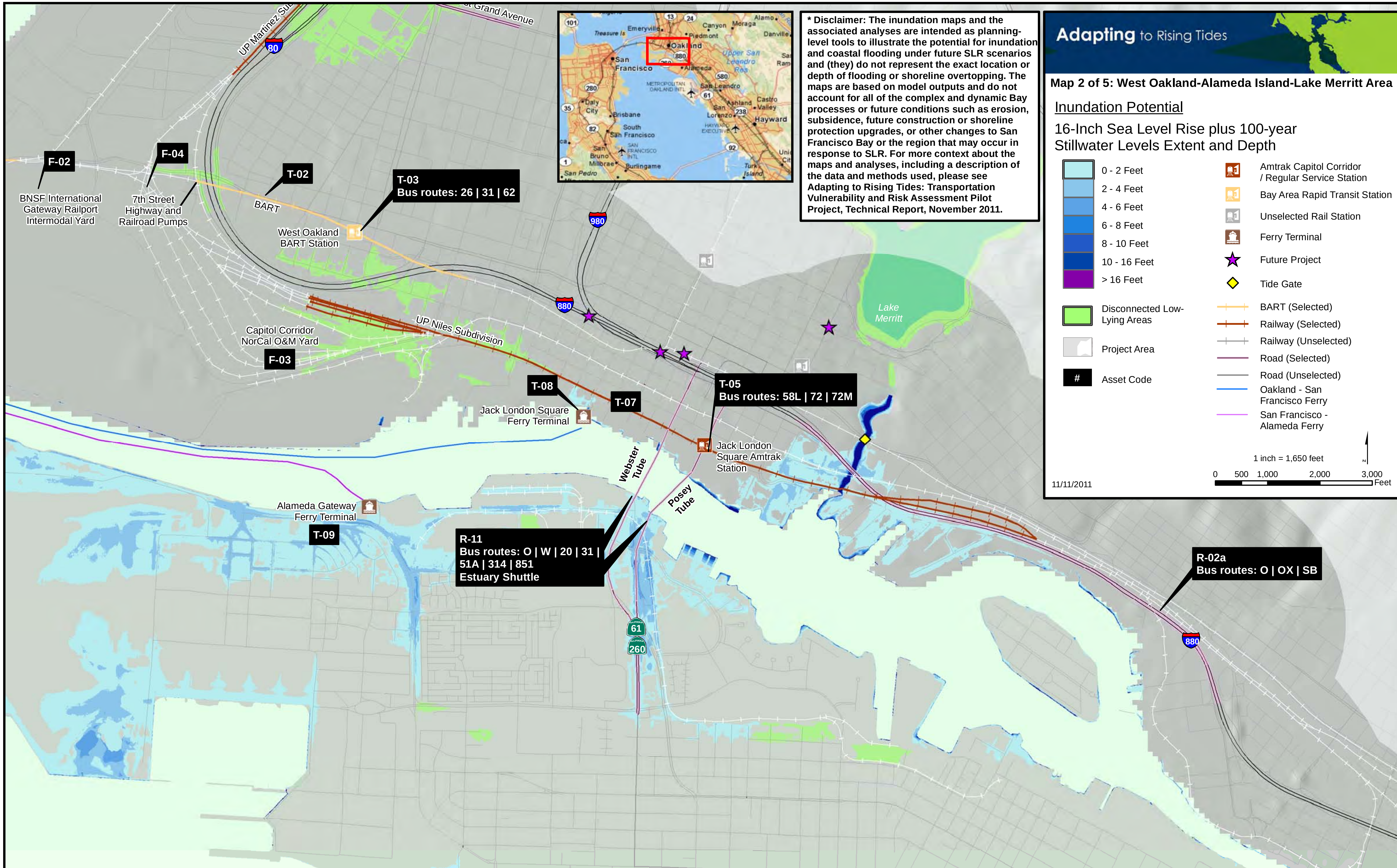
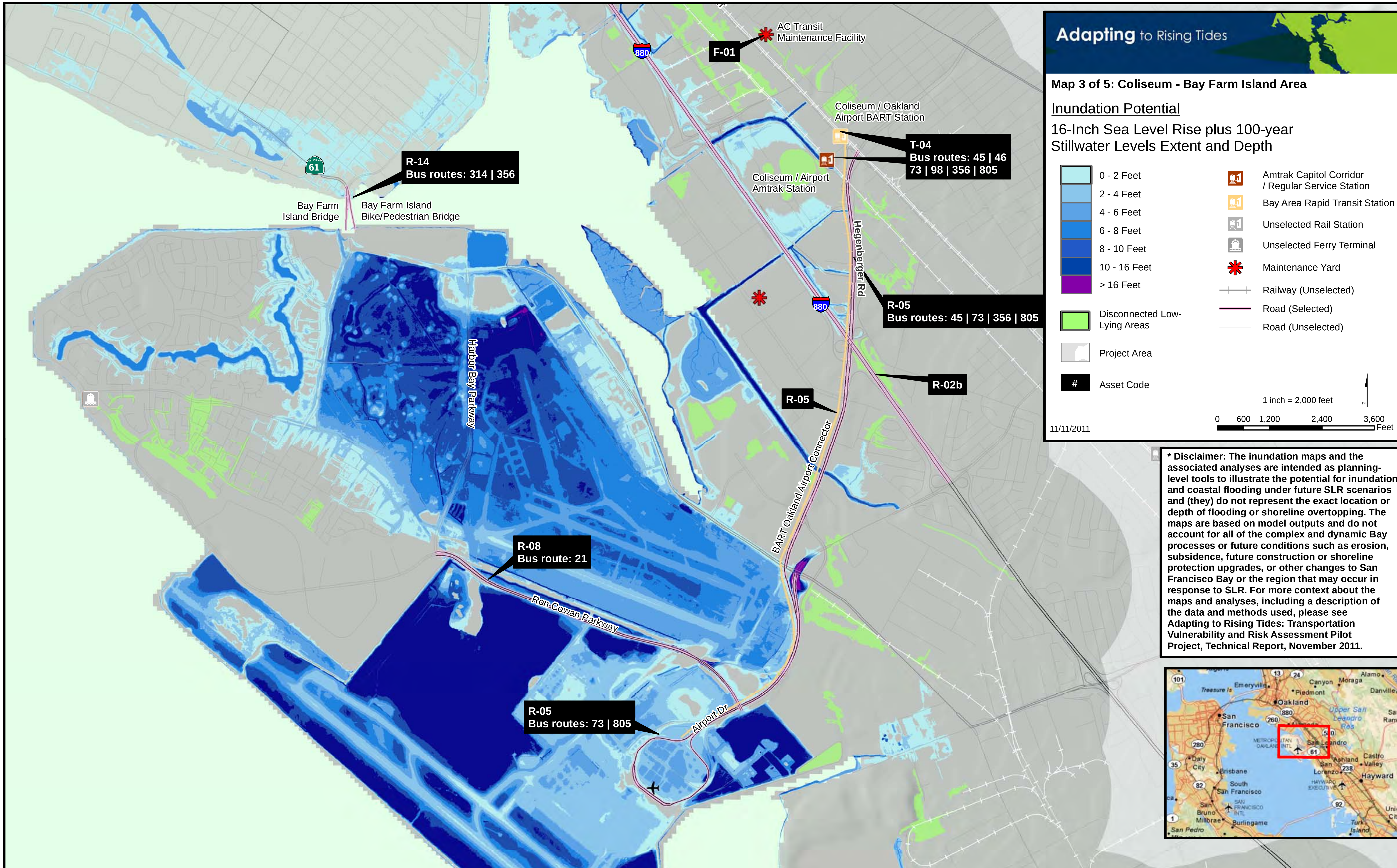
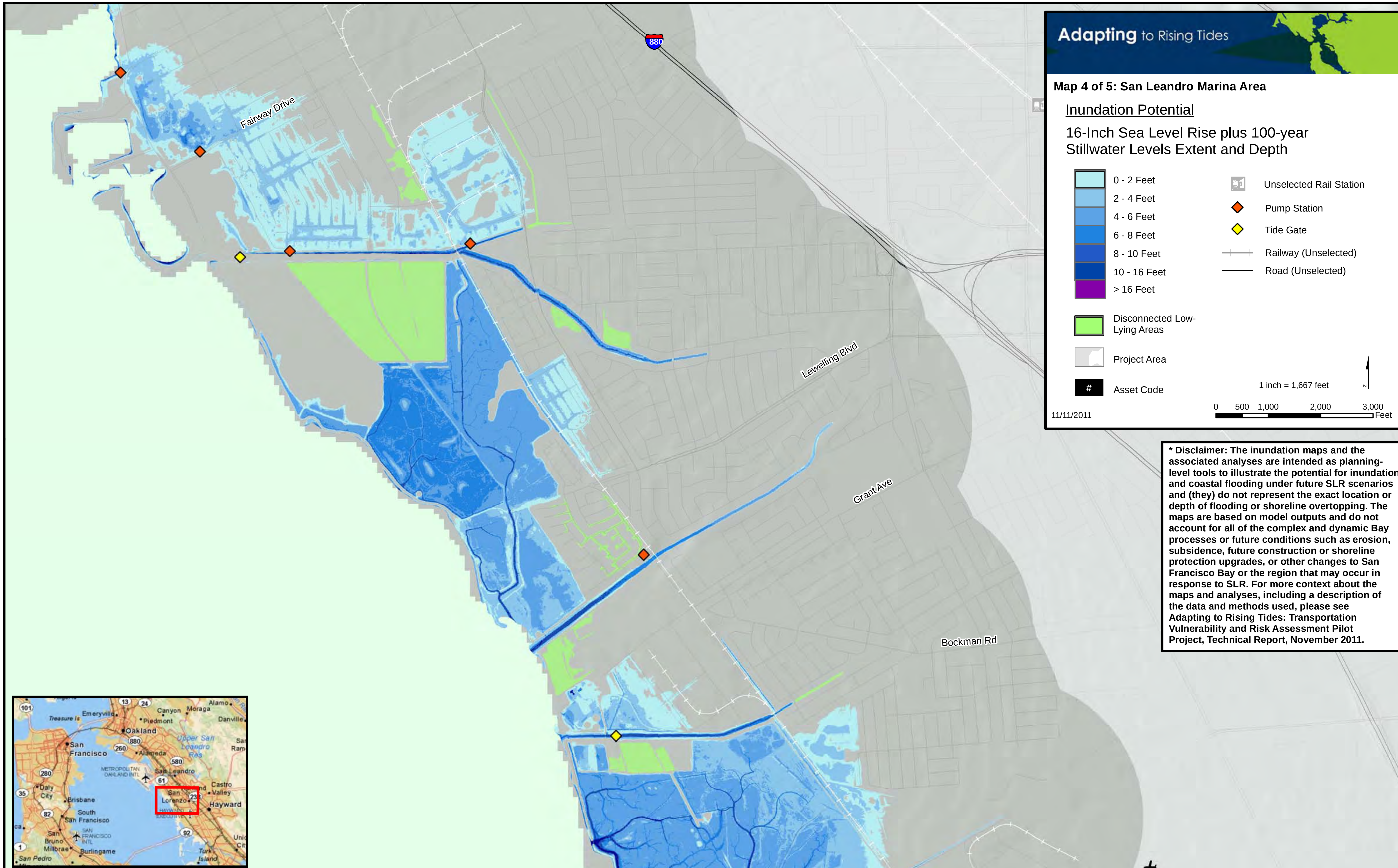

Adapting to Rising Tides
Map 5 of 5: North Union City Area
Inundation Potential
16-Inch MHHW Sea Level Rise Extent and Depth
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Disconnected Low-Lying Areas
Project Area
Asset Code
Future Project
Pump Station
Tide Gate
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 1,667 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
R-10
Bus Route: 86
Cabot Blvd.
R-03
92
Toll Plaza
San Mateo Bridge
R-13
Bus Route: M
SP Railroad
Industrial Blvd
880
San Francisco
Oakland
Hayward
San Leandro
Daly City
South San Francisco
Burlingame

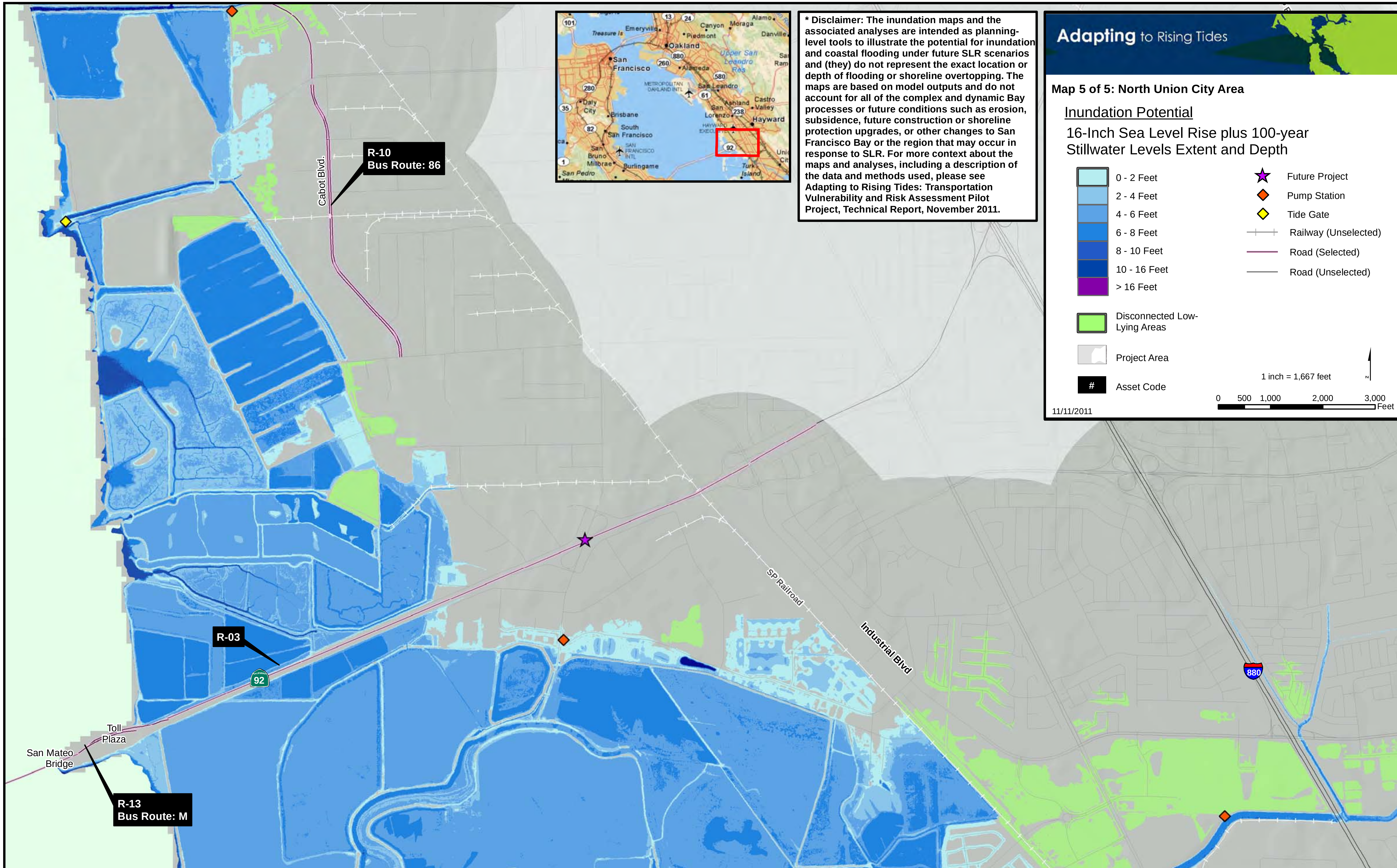

Adapting to Rising Tides
Map 1 of 5: Emeryville Crescent - I-80/880/580 Maze Area
Inundation Potential
16-Inch Sea Level Rise plus 100-year Stillwater Levels Extent and Depth
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Disconnected Low-Lying Areas
Project Area
Asset Code
Unselected Rail Station
Pump Station
BART (Selected)
Railway (Selected)
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 1,650 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
Northern Project Extent
R-06
Bus Route: EGR
R-01
Bus routes: C | F | FS | G | H | J | L | LA | EGR
Amtrak Thruway
R-12
Bus routes: 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
R-09
R-07
Bus route: 31
R-04
Bus route: NL
T-06
T-01
F-02
F-04
T-02
T-03
Bus routes: 26 | 31 | 62
Powell St
Toll Plaza
Burma Rd
Bay Bridge
Mandela Parkway
West Grand Avenue
UP Martinez Subdivision
BART Transbay Tube
BART
BNSF International Gateway Railport Intermodal Yard
7th Street Highway and Railroad Pumps
San Francisco Bay
80
580
880
980
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.

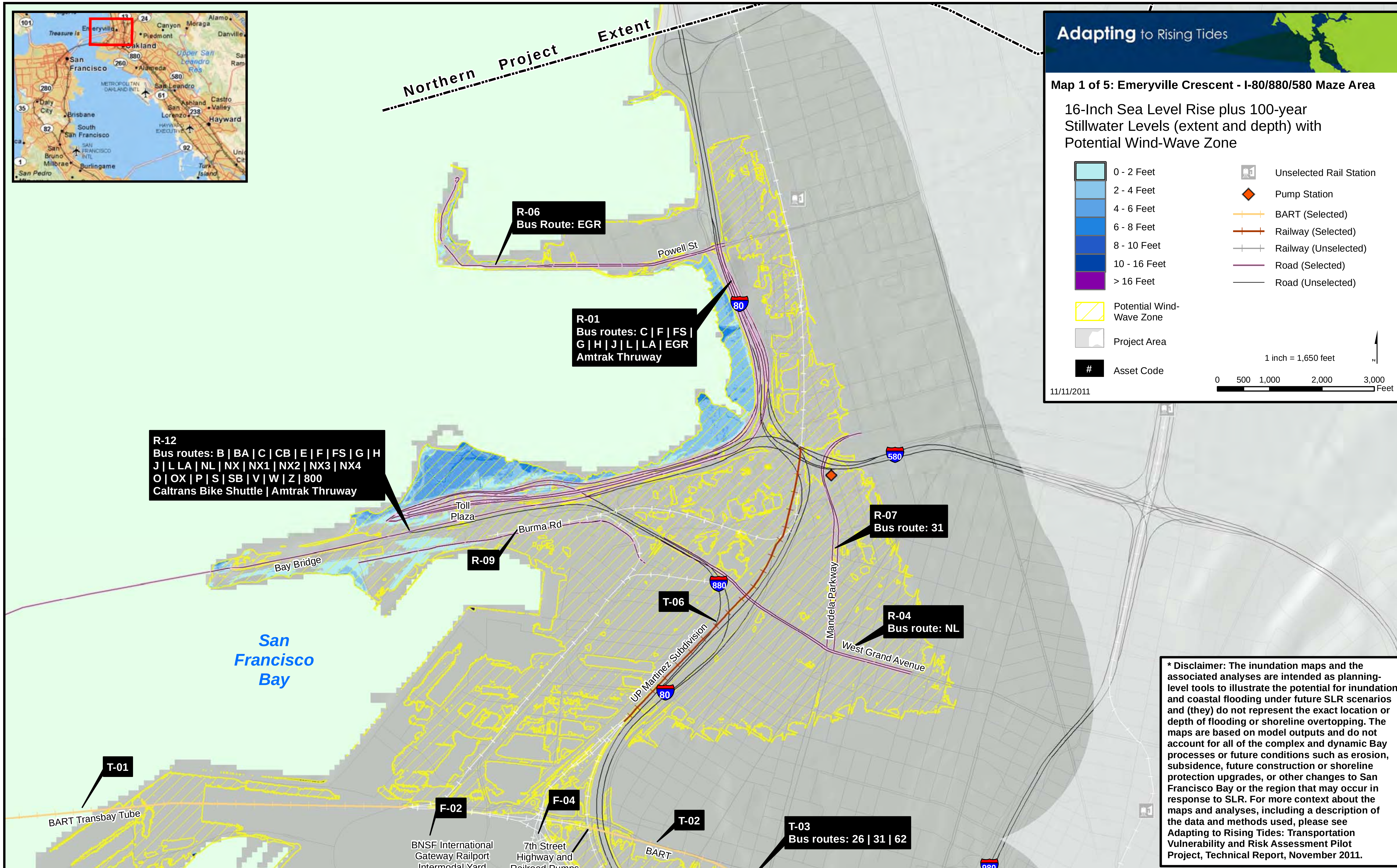

Adapting to Rising Tides
Map 2 of 5: West Oakland-Alameda Island-Lake Merritt Area
Inundation Potential
16-Inch Sea Level Rise plus 100-year Stillwater Levels Extent and Depth
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Disconnected Low-Lying Areas
Project Area
Asset Code
Amtrak Capitol Corridor / Regular Service Station
Bay Area Rapid Transit Station
Unselected Rail Station
Ferry Terminal
Future Project
Tide Gate
BART (Selected)
Railway (Selected)
Railway (Unselected)
Road (Selected)
Road (Unselected)
Oakland - San Francisco Ferry
San Francisco - Alameda Ferry
1 inch = 1,650 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
F-02
BNSF International Gateway Railport Intermodal Yard
F-04
7th Street Highway and Railroad Pumps
T-02
BART
T-03
Bus routes: 26 | 31 | 62
West Oakland BART Station
UP Martinez Sub
Grand Avenue
Capitol Corridor NorCal O&M Yard
F-03
UP Niles Subdivision
T-08
Jack London Square Ferry Terminal
T-07
T-05
Bus routes: 58L | 72 | 72M
Jack London Square Amtrak Station
Lake Merritt
Webster Tube
Posey Tube
Alameda Gateway Ferry Terminal
T-09
R-11
Bus routes: O | W | 20 | 31 | 51A | 314 | 851
Estuary Shuttle
R-02a
Bus routes: O | OX | SB
80
880
980
61
260
Emeryville
Piedmont
Oakland
San Francisco
Alameda
Treasure Is
Daly City
Brisbane
South San Francisco
San Bruno
Millbrae
Burlingame
San Pedro
San Leandro
San Lorenzo
Ashland
Castro Valley
Hayward
Canyon
Moraga
Danville
Alamo
Upper San Leandro Res
Metropolitan Oakland Intl
San Francisco Intl
Hayward Executive

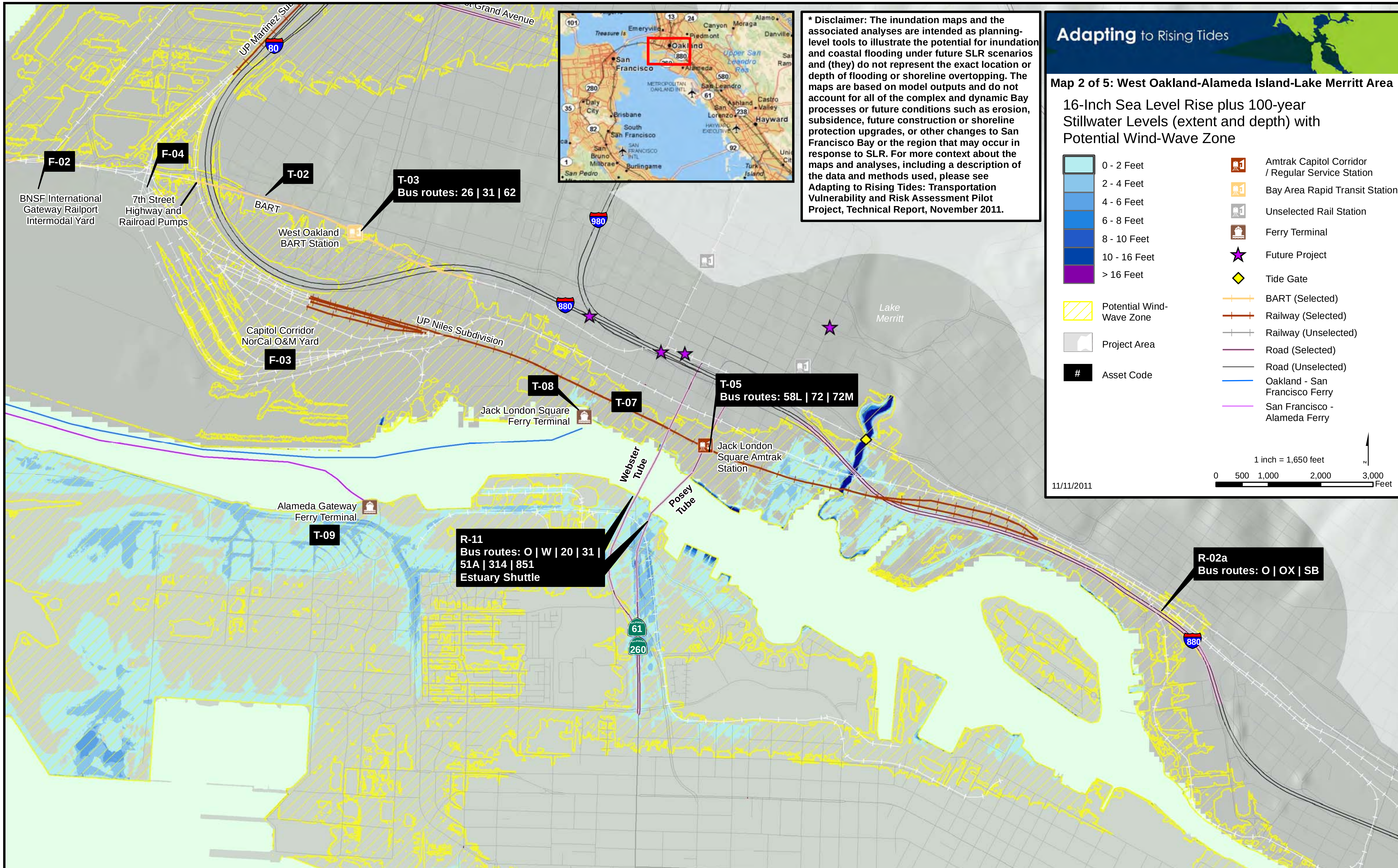

Adapting to Rising Tides
Map 3 of 5: Coliseum - Bay Farm Island Area
Inundation Potential
16-Inch Sea Level Rise plus 100-year Stillwater Levels Extent and Depth
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Disconnected Low-Lying Areas
Project Area
Asset Code
Amtrak Capitol Corridor / Regular Service Station
Bay Area Rapid Transit Station
Unselected Rail Station
Unselected Ferry Terminal
Maintenance Yard
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 2,000 feet
0 600 1,200 2,400 3,600 Feet
11/11/2011
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
AC Transit Maintenance Facility
F-01
Coliseum / Oakland Airport BART Station
T-04
Bus routes: 45 | 46 73 | 98 | 356 | 805
Coliseum / Airport Amtrak Station
R-14
Bus routes: 314 | 356
Bay Farm Island Bridge
Bay Farm Island Bike/Pedestrian Bridge
Hegenberger Rd
R-05
Bus routes: 45 | 73 | 356 | 805
R-02b
R-05
Harbor Bay Parkway
BART Oakland Airport Connector
R-08
Bus route: 21
Ron Cowan Parkway
R-05
Bus routes: 73 | 805
Airport Dr
880
61
Treasure Is
Emeryville
Piedmont
Oakland
San Francisco
Daly City
Brisbane
South San Francisco
San Bruno
Millbrae
Burlingame
San Pedro
San Leandro
Ashland
San Lorenzo
Castro Valley
Hayward
Canyon
Moraga
Alamo
Danville
Upper San Leandro Res



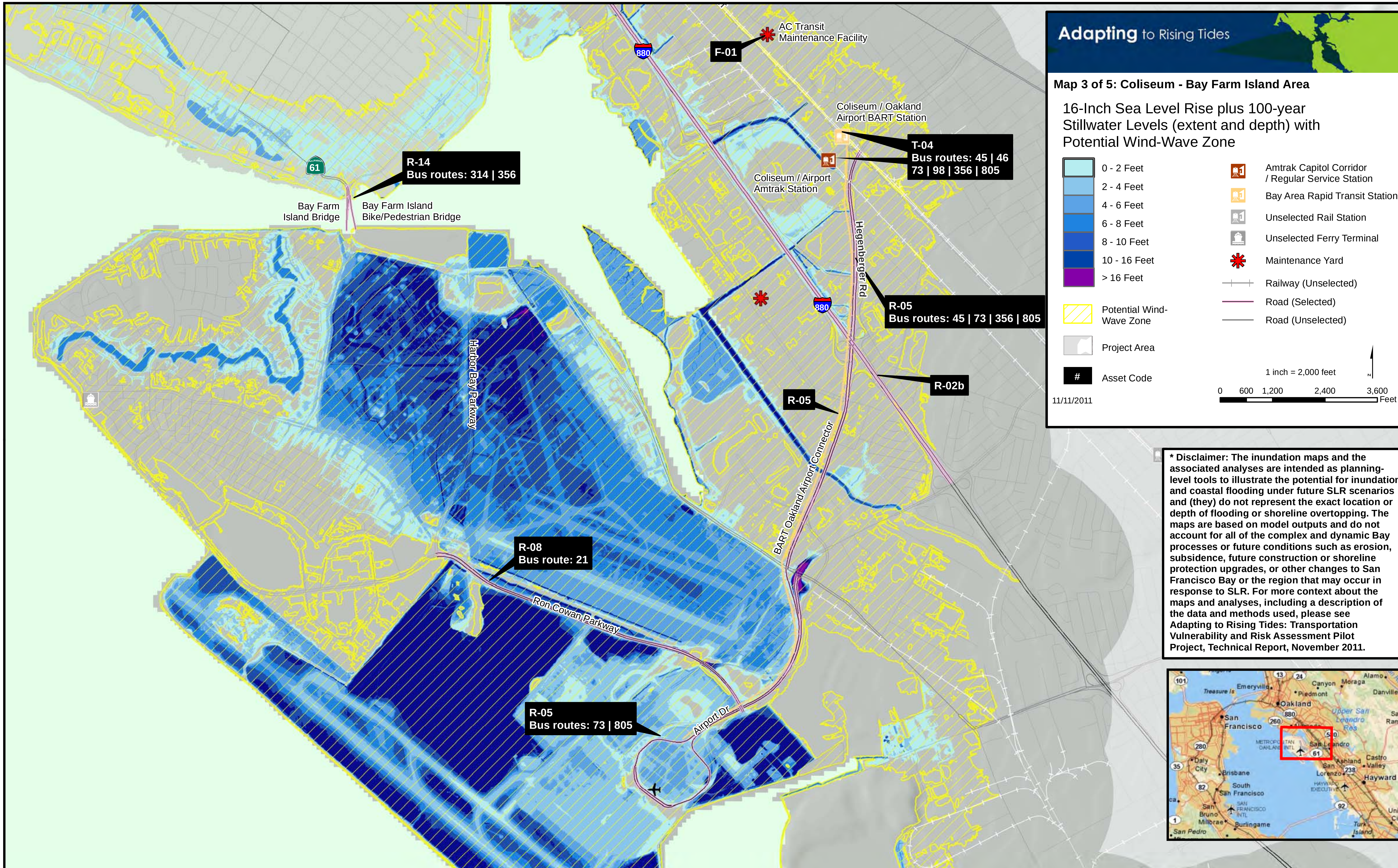
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.

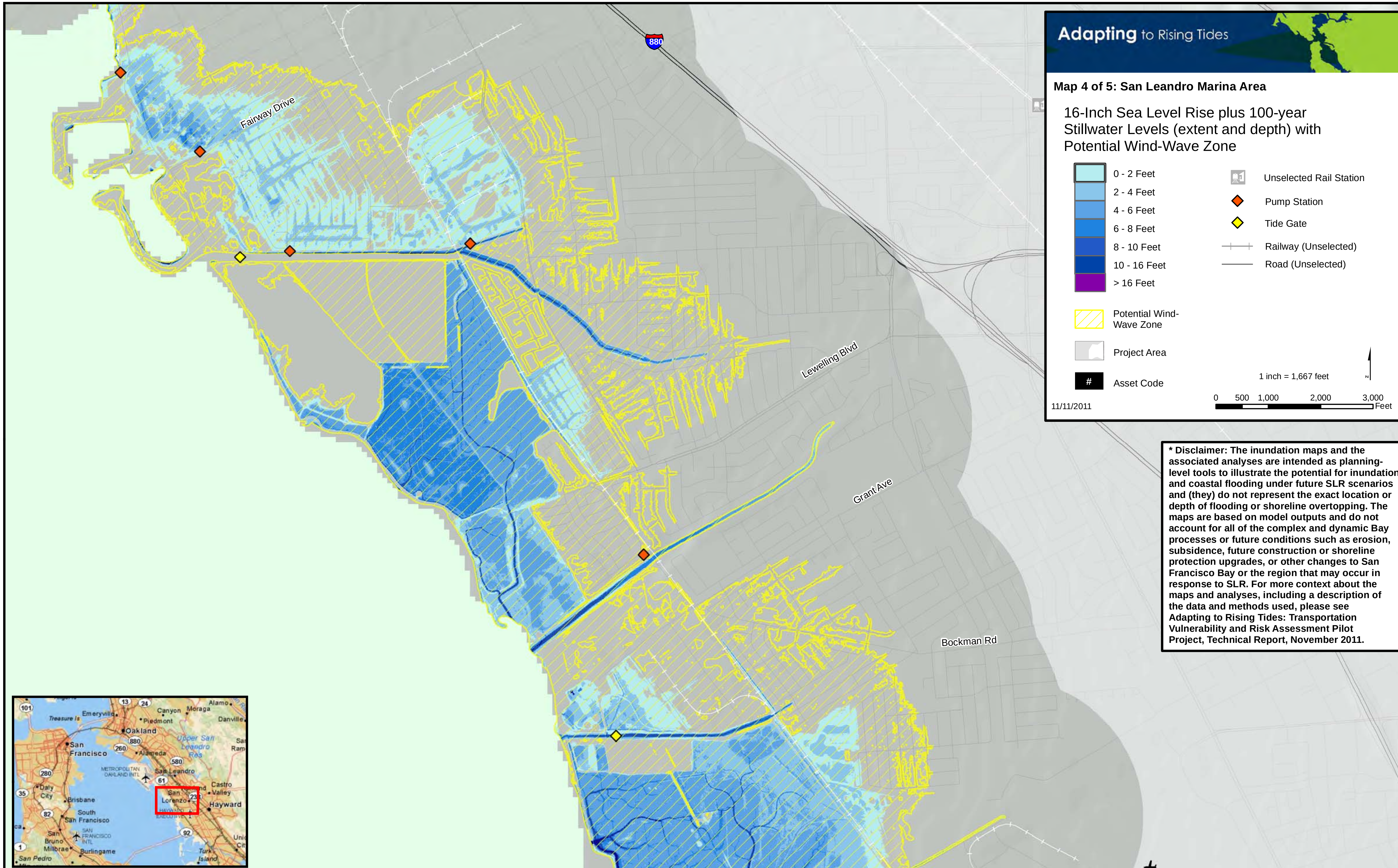

Adapting to Rising Tides
Map 5 of 5: North Union City Area
Inundation Potential
16-Inch Sea Level Rise plus 100-year Stillwater Levels Extent and Depth
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Disconnected Low-Lying Areas
Project Area
Asset Code
Future Project
Pump Station
Tide Gate
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 1,667 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
R-10
Bus Route: 86
Cabot Blvd.
R-03
R-13
Bus Route: M
Toll Plaza
San Mateo Bridge
SP Railroad
Industrial Blvd
92
880
Oakland
San Francisco
Hayward
San Leandro
Daly City
South San Francisco
Brisbane
Burlingame
Millbrae
San Bruno
Alameda
Emeryville
Piedmont
Moraga
Canyon
Castro Valley
Ashland
San Lorenzo
Upper San Leandro Res
Treasure Is
San Pedro

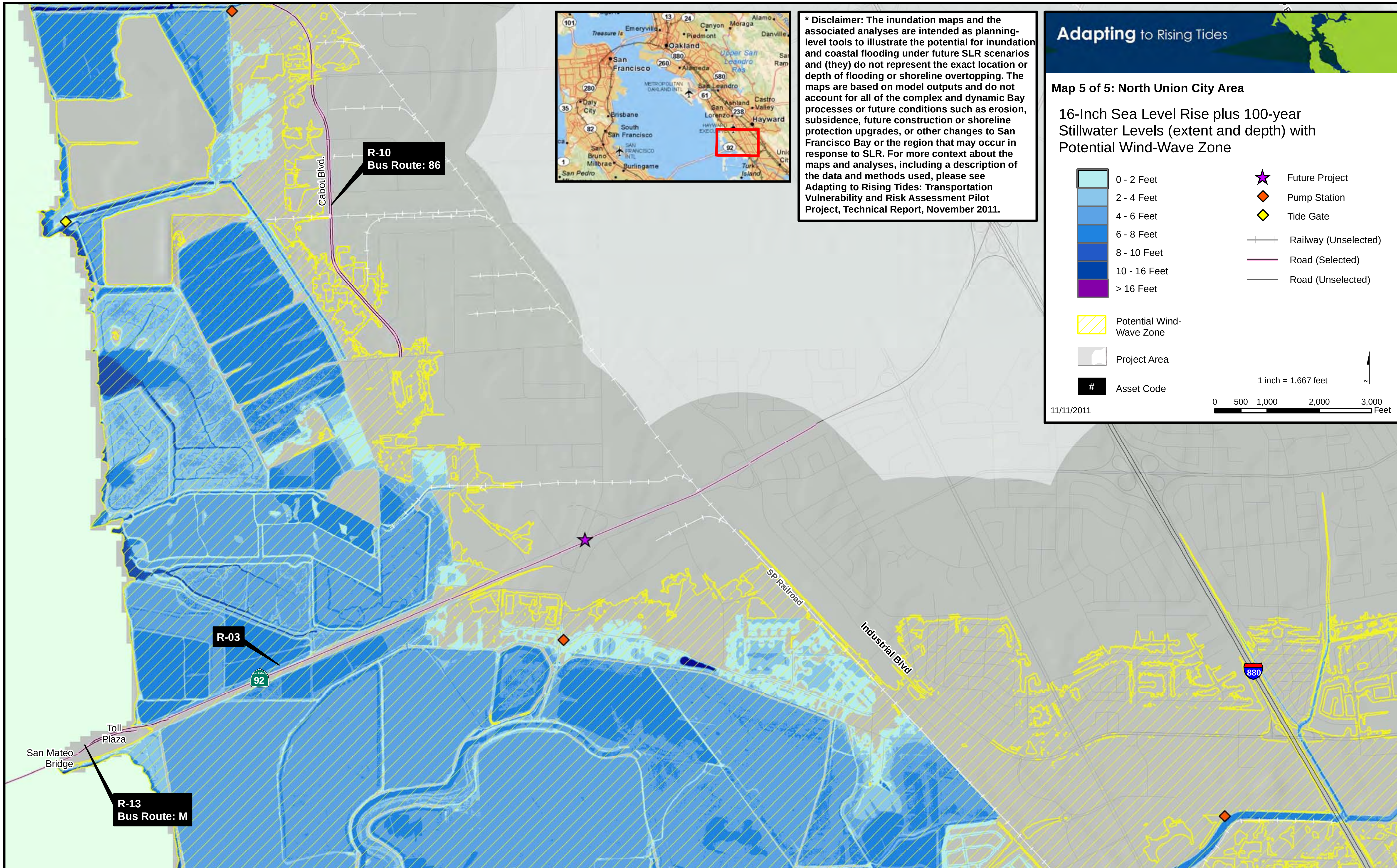

Adapting to Rising Tides
Map 1 of 5: Emeryville Crescent - I-80/880/580 Maze Area
16-Inch Sea Level Rise plus 100-year Stillwater Levels (extent and depth) with Potential Wind-Wave Zone
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Potential Wind-Wave Zone
Project Area
Asset Code
Unselected Rail Station
Pump Station
BART (Selected)
Railway (Selected)
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 1,650 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
Northern Project Extent
R-06
Bus Route: EGR
Powell St
R-01
Bus routes: C | F | FS | G | H | J | L | LA | EGR
Amtrak Thruway
R-12
Bus routes: 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
Toll Plaza
Burma Rd
Bay Bridge
R-09
R-07
Bus route: 31
Mandela Parkway
R-04
Bus route: NL
West Grand Avenue
T-06
UP Martinez Subdivision
San Francisco Bay
T-01
BART Transbay Tube
F-02
BNSF International Gateway Railport Intermodal Yard
F-04
7th Street Highway and Railroad Pumps
T-02
BART
T-03
Bus routes: 26 | 31 | 62
80
580
880
980
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.



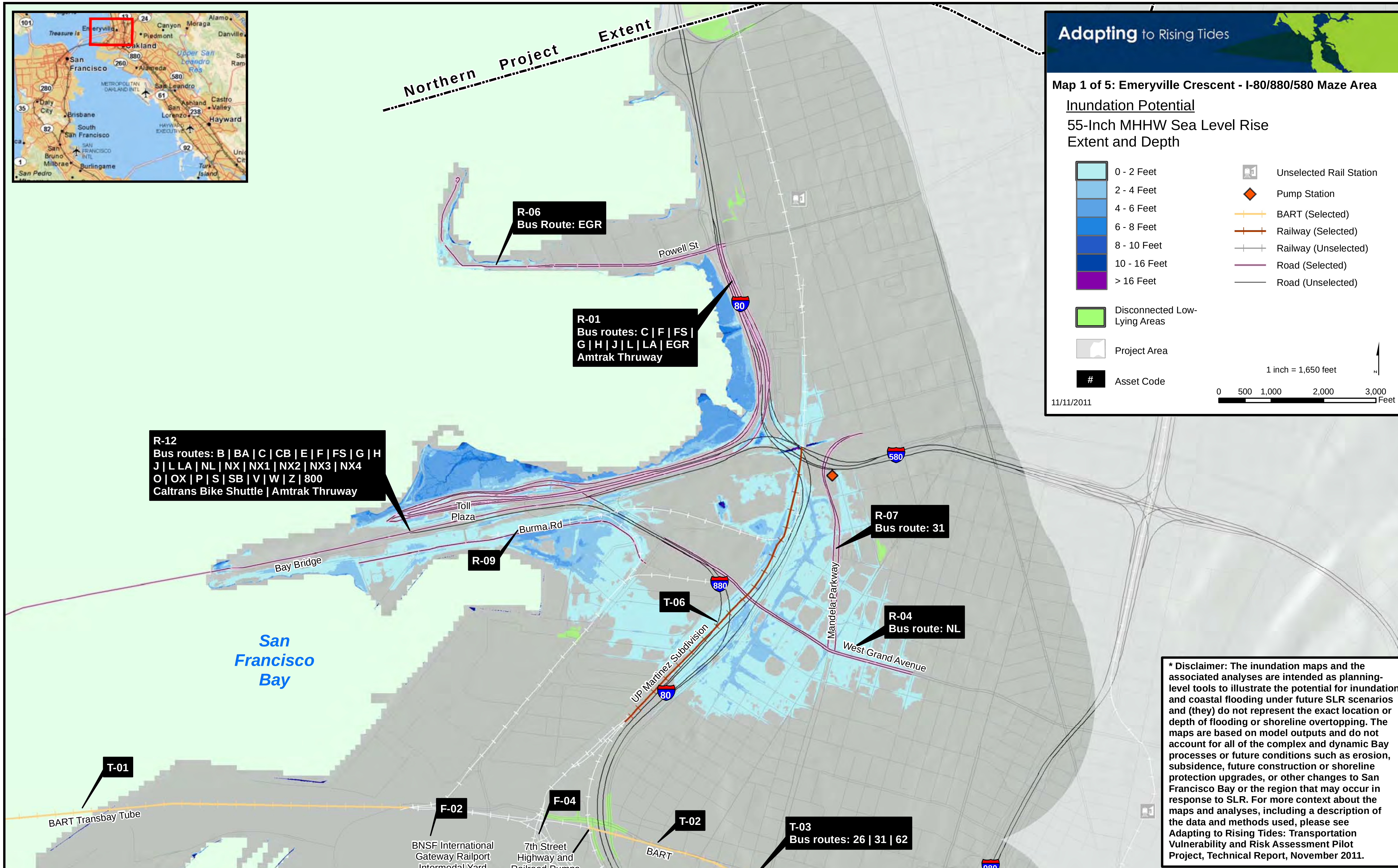
Adapting to Rising Tides
Map 2 of 5: West Oakland-Alameda Island-Lake Merritt Area
16-Inch Sea Level Rise plus 100-year Stillwater Levels (extent and depth) with Potential Wind-Wave Zone
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Potential Wind-Wave Zone
Project Area
Asset Code
Amtrak Capitol Corridor / Regular Service Station
Bay Area Rapid Transit Station
Unselected Rail Station
Ferry Terminal
Future Project
Tide Gate
BART (Selected)
Railway (Selected)
Railway (Unselected)
Road (Selected)
Road (Unselected)
Oakland - San Francisco Ferry
San Francisco - Alameda Ferry
1 inch = 1,650 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
F-02
BNSF International Gateway Railport Intermodal Yard
F-04
7th Street Highway and Railroad Pumps
T-02
BART
T-03
Bus routes: 26 | 31 | 62
West Oakland BART Station
UP Martinez Sub
Grand Avenue
Capitol Corridor NorCal O&M Yard
F-03
UP Niles Subdivision
T-08
Jack London Square Ferry Terminal
T-07
T-05
Bus routes: 58L | 72 | 72M
Jack London Square Amtrak Station
Lake Merritt
Webster Tube
Posey Tube
Alameda Gateway Ferry Terminal
T-09
R-11
Bus routes: O | W | 20 | 31 | 51A | 314 | 851
Estuary Shuttle
R-02a
Bus routes: O | OX | SB
80
880
980
61
260


Adapting to Rising Tides
Map 3 of 5: Coliseum - Bay Farm Island Area
16-Inch Sea Level Rise plus 100-year Stillwater Levels (extent and depth) with Potential Wind-Wave Zone
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Potential Wind-Wave Zone
Project Area
Asset Code
Amtrak Capitol Corridor / Regular Service Station
Bay Area Rapid Transit Station
Unselected Rail Station
Unselected Ferry Terminal
Maintenance Yard
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 2,000 feet
0 600 1,200 2,400 3,600 Feet
11/11/2011
AC Transit Maintenance Facility
F-01
Coliseum / Oakland Airport BART Station
T-04
Bus routes: 45 | 46 73 | 98 | 356 | 805
Coliseum / Airport Amtrak Station
R-14
Bus routes: 314 | 356
Bay Farm Island Bridge
Bay Farm Island Bike/Pedestrian Bridge
Hegenberger Rd
R-05
Bus routes: 45 | 73 | 356 | 805
R-02b
R-05
Harbor Bay Parkway
BART Oakland Airport Connector
R-08
Bus route: 21
Ron Cowan Parkway
R-05
Bus routes: 73 | 805
Airport Dr
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
Oakland
San Francisco
San Leandro
Hayward

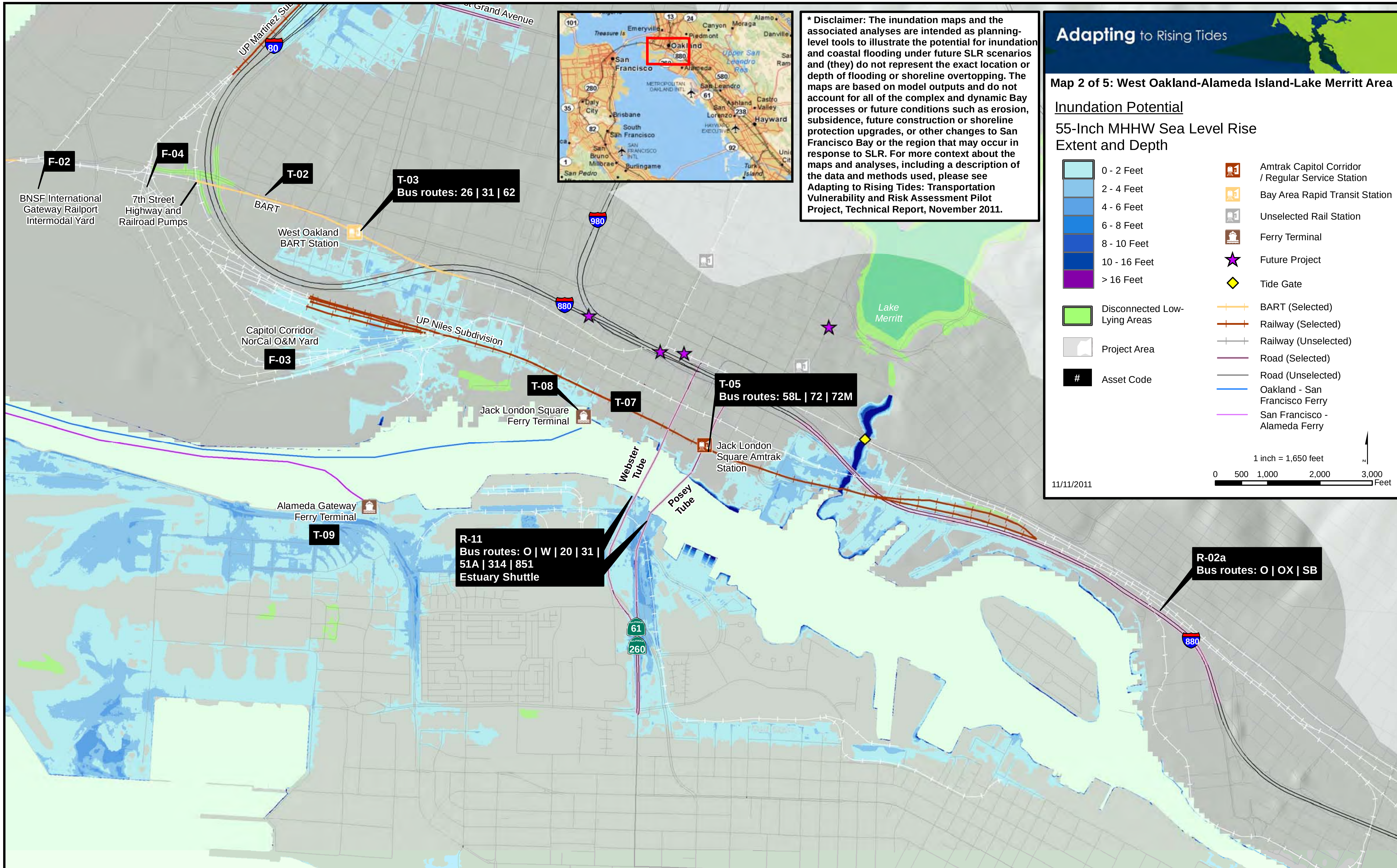

Adapting to Rising Tides
Map 4 of 5: San Leandro Marina Area
16-Inch Sea Level Rise plus 100-year Stillwater Levels (extent and depth) with Potential Wind-Wave Zone
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Potential Wind-Wave Zone
Project Area
Asset Code
Unselected Rail Station
Pump Station
Tide Gate
Railway (Unselected)
Road (Unselected)
1 inch = 1,667 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
Fairway Drive
Lewelling Blvd
Grant Ave
Bockman Rd
880
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
Oakland
San Francisco
San Leandro
San Lorenzo
Hayward
Alameda
Castro Valley
Brisbane
South San Francisco
Burlingame
Daly City
Emeryville
Piedmont
Moraga
Danville



Adapting to Rising Tides
Map 5 of 5: North Union City Area
16-Inch Sea Level Rise plus 100-year Stillwater Levels (extent and depth) with Potential Wind-Wave Zone
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Potential Wind-Wave Zone
Project Area
Asset Code
Future Project
Pump Station
Tide Gate
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 1,667 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
R-10
Bus Route: 86
Cabot Blvd.
R-03
92
Toll Plaza
San Mateo Bridge
R-13
Bus Route: M
SP Railroad
Industrial Blvd
880
San Francisco
Oakland
Emeryville
Piedmont
Alameda
San Leandro
San Lorenzo
Ashland
Castro Valley
Hayward
Daly City
Brisbane
South San Francisco
San Bruno
Millbrae
Burlingame
San Pedro



Adapting to Rising Tides
Map 1 of 5: Emeryville Crescent - I-80/880/580 Maze Area
Inundation Potential
55-Inch MHHW Sea Level Rise Extent and Depth
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Disconnected Low-Lying Areas
Project Area
Asset Code
Unselected Rail Station
Pump Station
BART (Selected)
Railway (Selected)
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 1,650 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
Northern Project Extent
R-06
Bus Route: EGR
Powell St
R-01
Bus routes: C | F | FS | G | H | J | L | LA | EGR
Amtrak Thruway
R-12
Bus routes: 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
Toll Plaza
Burma Rd
Bay Bridge
R-09
R-07
Bus route: 31
Mandela Parkway
R-04
Bus route: NL
West Grand Avenue
T-06
UP Martinez Subdivision
San Francisco Bay
T-01
BART Transbay Tube
F-02
BNSF International Gateway Railport Intermodal Yard
F-04
7th Street Highway and Railroad Pumps
T-02
BART
T-03
Bus routes: 26 | 31 | 62
80
880
580
980
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.



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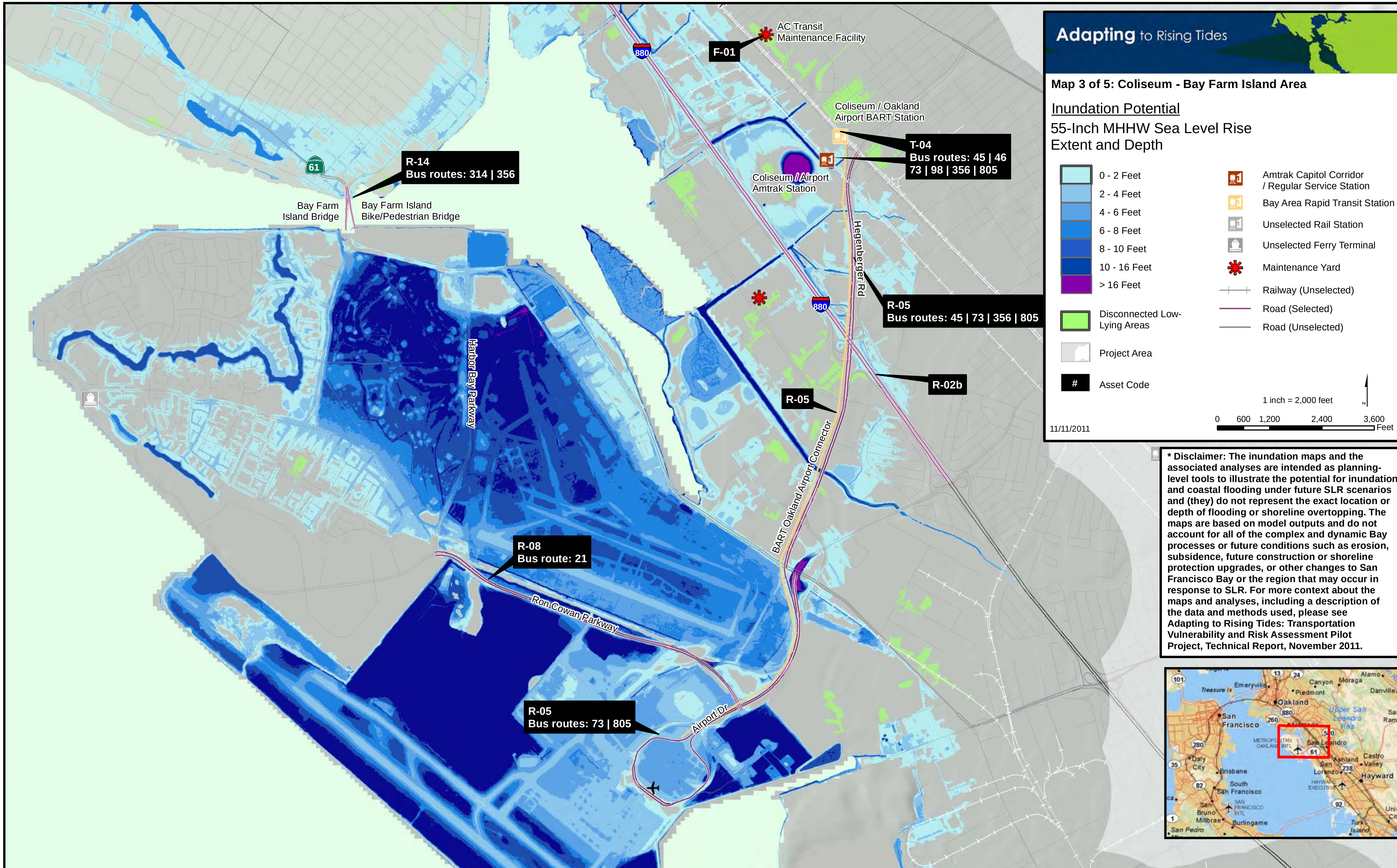
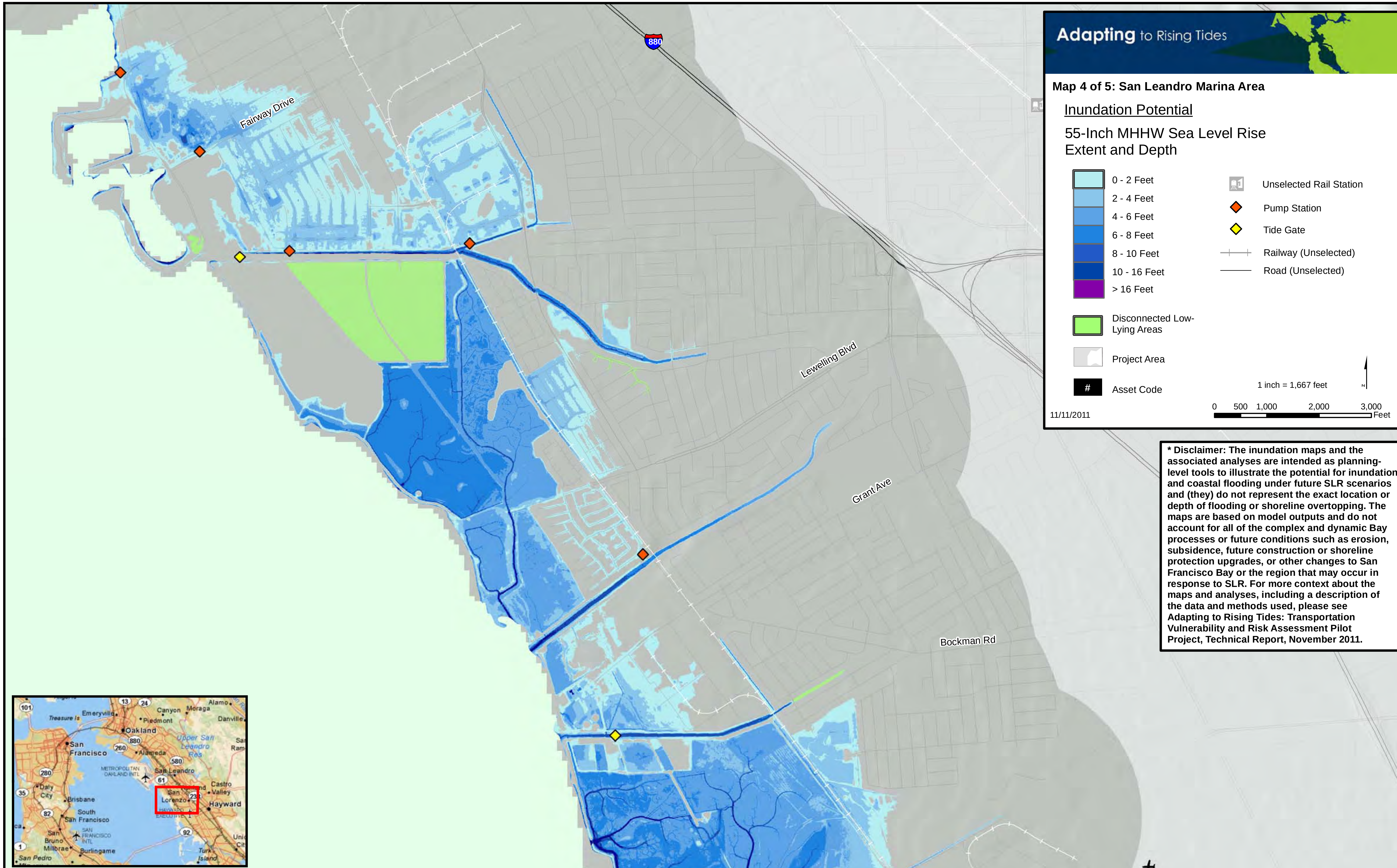
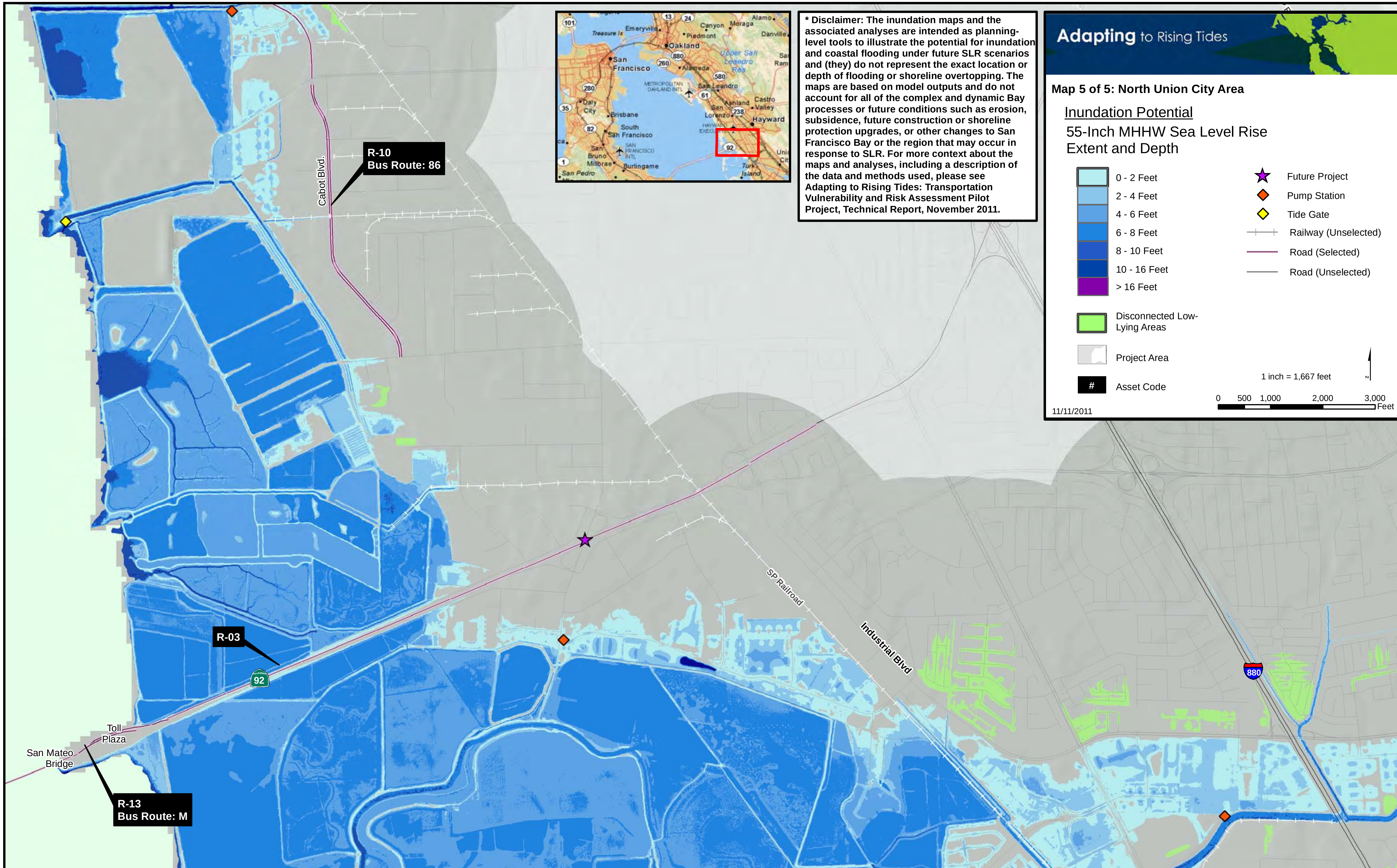
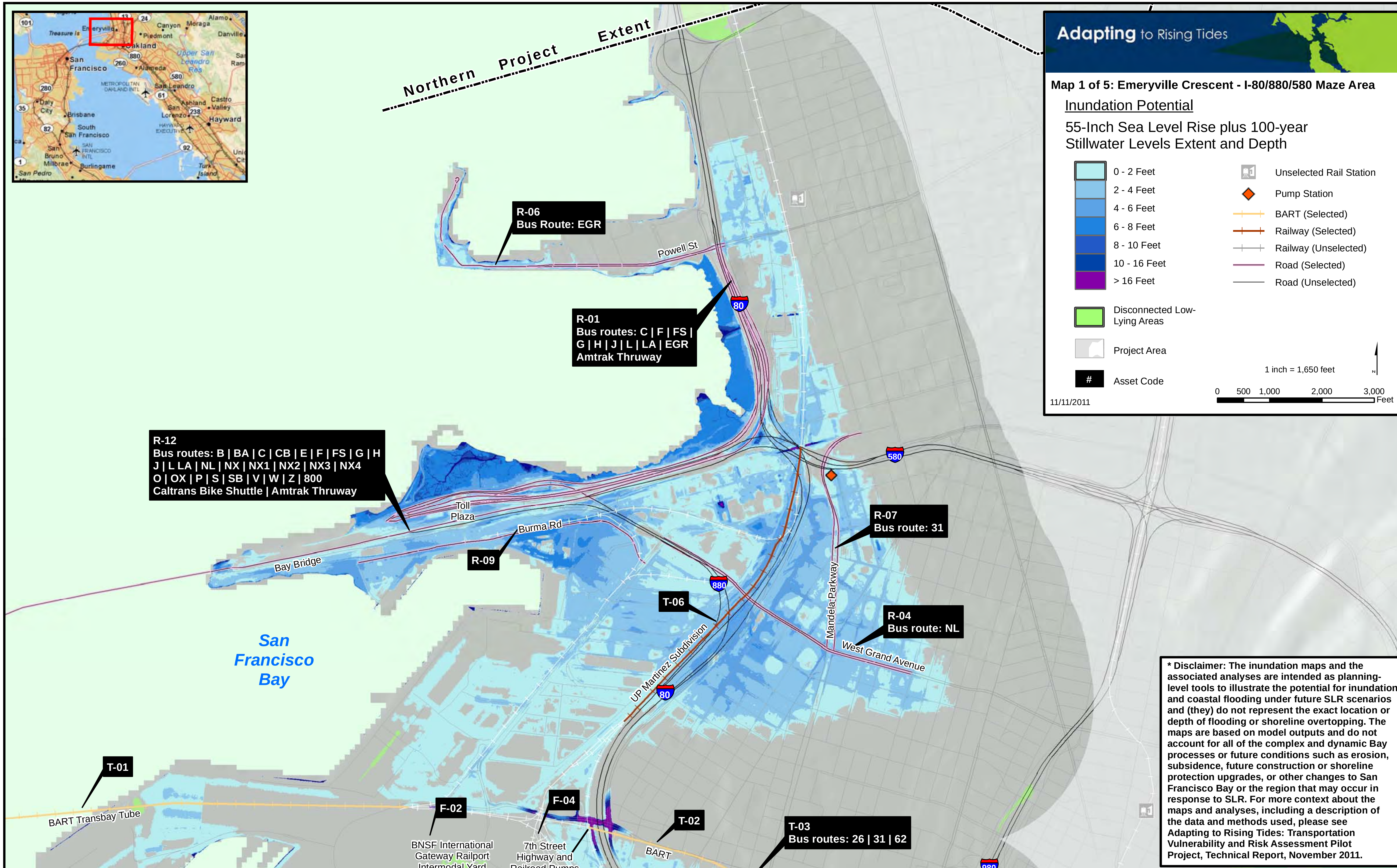
Adapting to Rising Tides
Map 2 of 5: West Oakland-Alameda Island-Lake Merritt Area
Inundation Potential
55-Inch MHHW Sea Level Rise Extent and Depth
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Disconnected Low-Lying Areas
Project Area
Asset Code
Amtrak Capitol Corridor / Regular Service Station
Bay Area Rapid Transit Station
Unselected Rail Station
Ferry Terminal
Future Project
Tide Gate
BART (Selected)
Railway (Selected)
Railway (Unselected)
Road (Selected)
Road (Unselected)
Oakland - San Francisco Ferry
San Francisco - Alameda Ferry
1 inch = 1,650 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
F-02
BNSF International Gateway Railport Intermodal Yard
F-04
7th Street Highway and Railroad Pumps
T-02
BART
T-03
Bus routes: 26 | 31 | 62
West Oakland BART Station
UP Martinez Sub
Grand Avenue
Capitol Corridor NorCal O&M Yard
F-03
UP Niles Subdivision
T-08
Jack London Square Ferry Terminal
T-07
T-05
Bus routes: 58L | 72 | 72M
Jack London Square Amtrak Station
Lake Merritt
Webster Tube
Posey Tube
Alameda Gateway Ferry Terminal
T-09
R-11
Bus routes: O | W | 20 | 31 | 51A | 314 | 851
Estuary Shuttle
R-02a
Bus routes: O | OX | SB
80
880
980
61
260



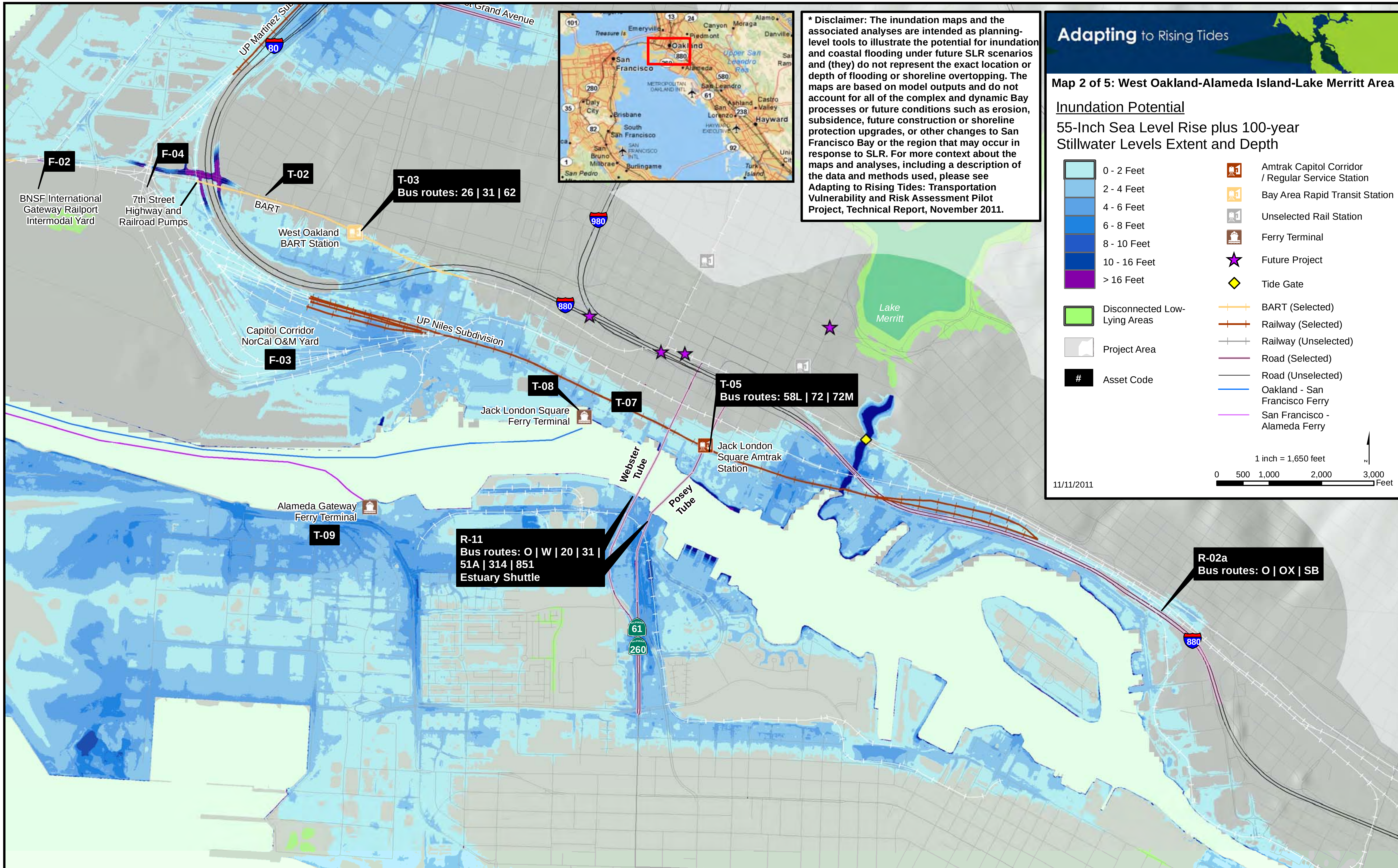
Adapting to Rising Tides
Map 3 of 5: Coliseum - Bay Farm Island Area
Inundation Potential
55-Inch MHHW Sea Level Rise
Extent and Depth
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Disconnected Low-Lying Areas
Project Area
Asset Code
Amtrak Capitol Corridor / Regular Service Station
Bay Area Rapid Transit Station
Unselected Rail Station
Unselected Ferry Terminal
Maintenance Yard
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 2,000 feet
0 600 1,200 2,400 3,600 Feet
11/11/2011
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
AC Transit Maintenance Facility
F-01
Coliseum / Oakland Airport BART Station
T-04
Bus routes: 45 | 46 73 | 98 | 356 | 805
Coliseum / Airport Amtrak Station
R-14
Bus routes: 314 | 356
Bay Farm Island Bridge
Bay Farm Island Bike/Pedestrian Bridge
Hegenberger Rd
R-05
Bus routes: 45 | 73 | 356 | 805
R-02b
R-05
BART Oakland Airport Connector
Harbor Bay Parkway
R-08
Bus route: 21
Ron Cowan Parkway
R-05
Bus routes: 73 | 805
Airport Dr

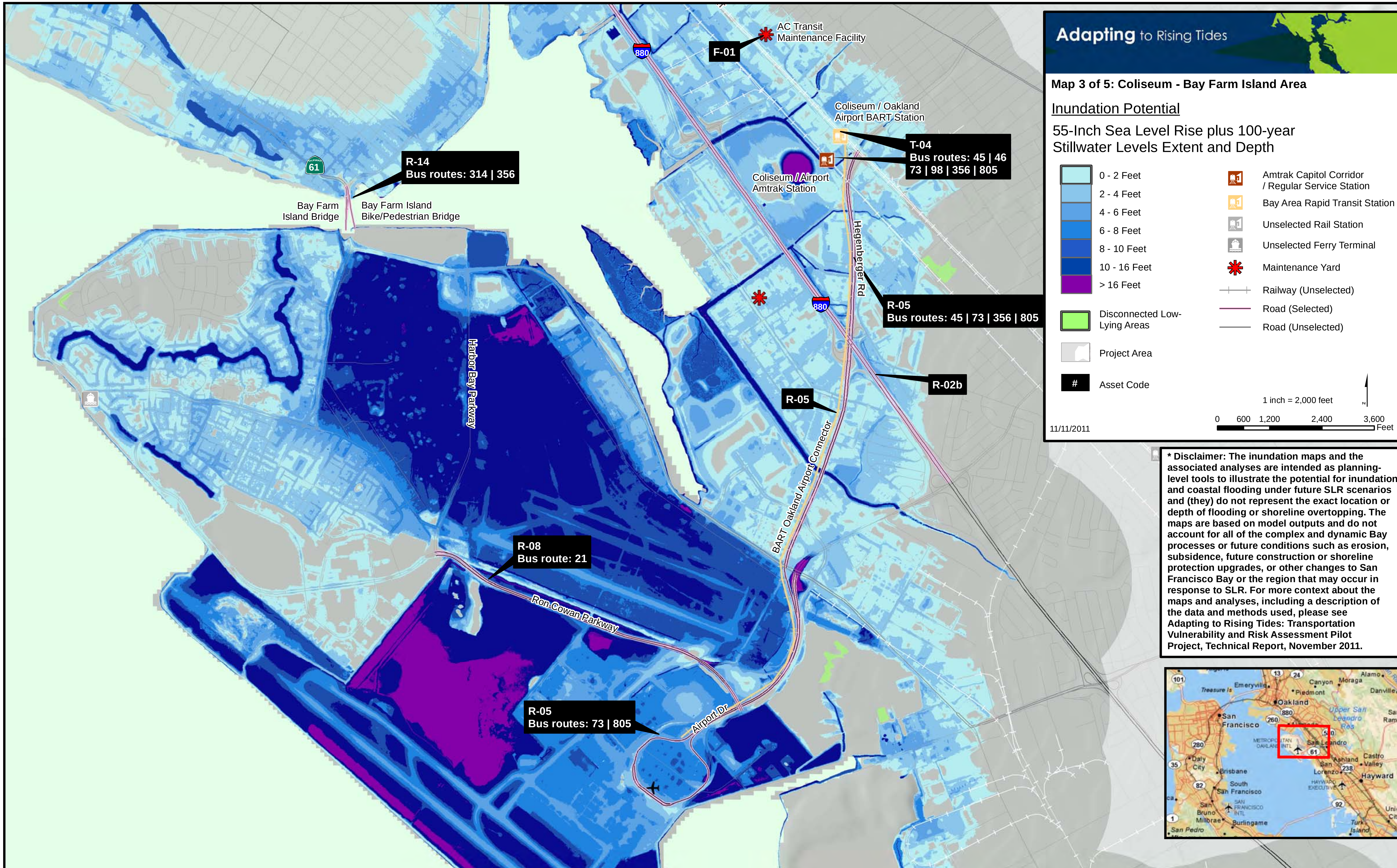

Adapting to Rising Tides
Map 4 of 5: San Leandro Marina Area
Inundation Potential
55-Inch MHHW Sea Level Rise
Extent and Depth
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Disconnected Low-Lying Areas
Project Area
Asset Code
Unselected Rail Station
Pump Station
Tide Gate
Railway (Unselected)
Road (Unselected)
1 inch = 1,667 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
880
Fairway Drive
Lewelling Blvd
Grant Ave
Bockman Rd
Oakland
San Francisco
San Leandro
San Lorenzo
Hayward
Alameda
Emeryville
Piedmont
Daly City
Brisbane
South San Francisco
San Bruno
Millbrae
Burlingame
Castro Valley
Moraga
Danville
Alamo
Canyon
Treasure Is
San Pedro

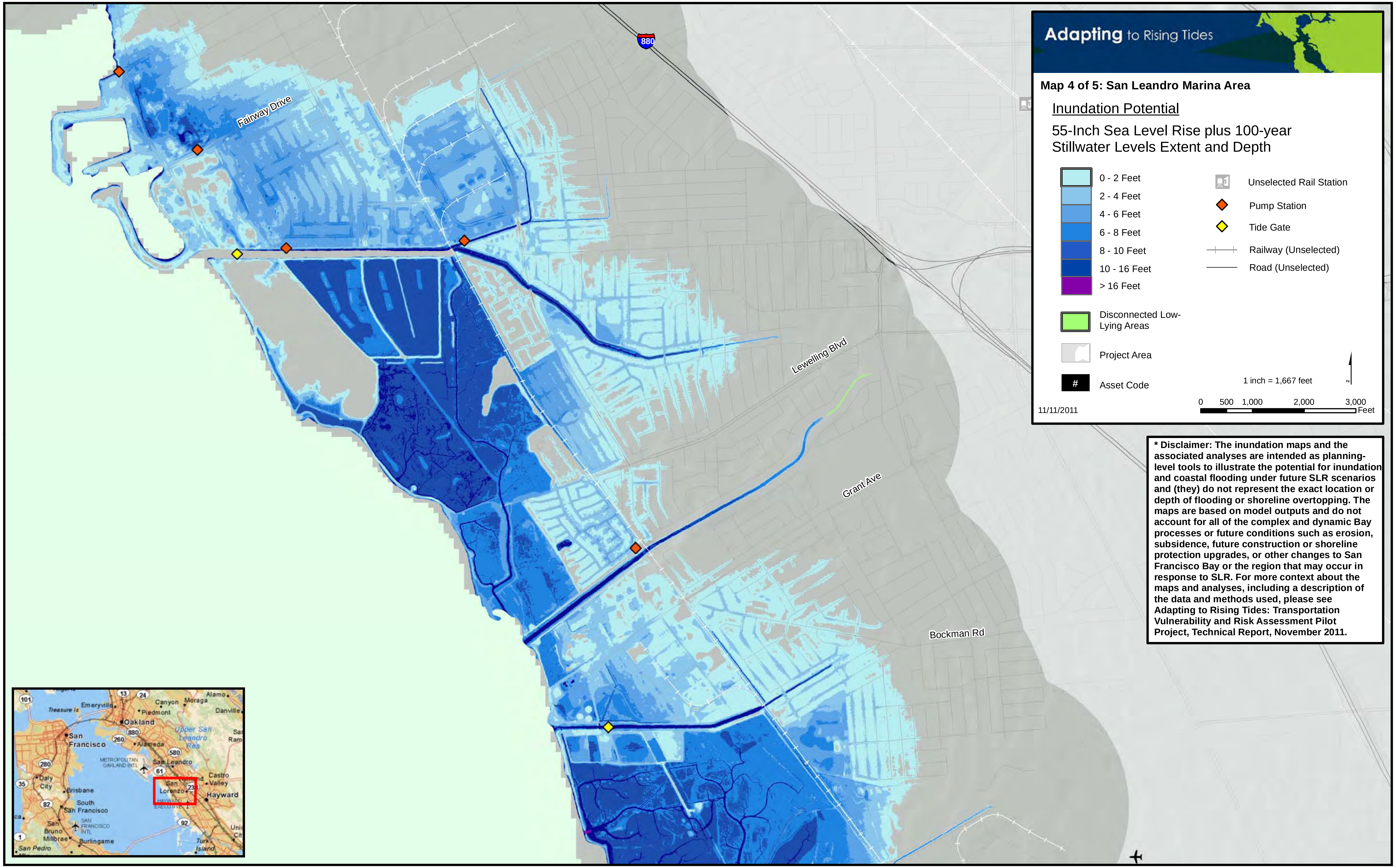

* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
Adapting to Rising Tides
Map 5 of 5: North Union City Area
Inundation Potential
55-Inch MHHW Sea Level Rise
Extent and Depth
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Disconnected Low-Lying Areas
Project Area
Asset Code
Future Project
Pump Station
Tide Gate
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 1,667 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
R-10
Bus Route: 86
Cabot Blvd.
R-03
92
Toll Plaza
San Mateo Bridge
R-13
Bus Route: M
SP Railroad
Industrial Blvd
880
San Francisco
Oakland
Hayward
San Leandro
Daly City
South San Francisco
San Bruno
Millbrae
Burlingame
San Lorenzo
Castro Valley
Alameda
Emeryville
Piedmont
Brisbane

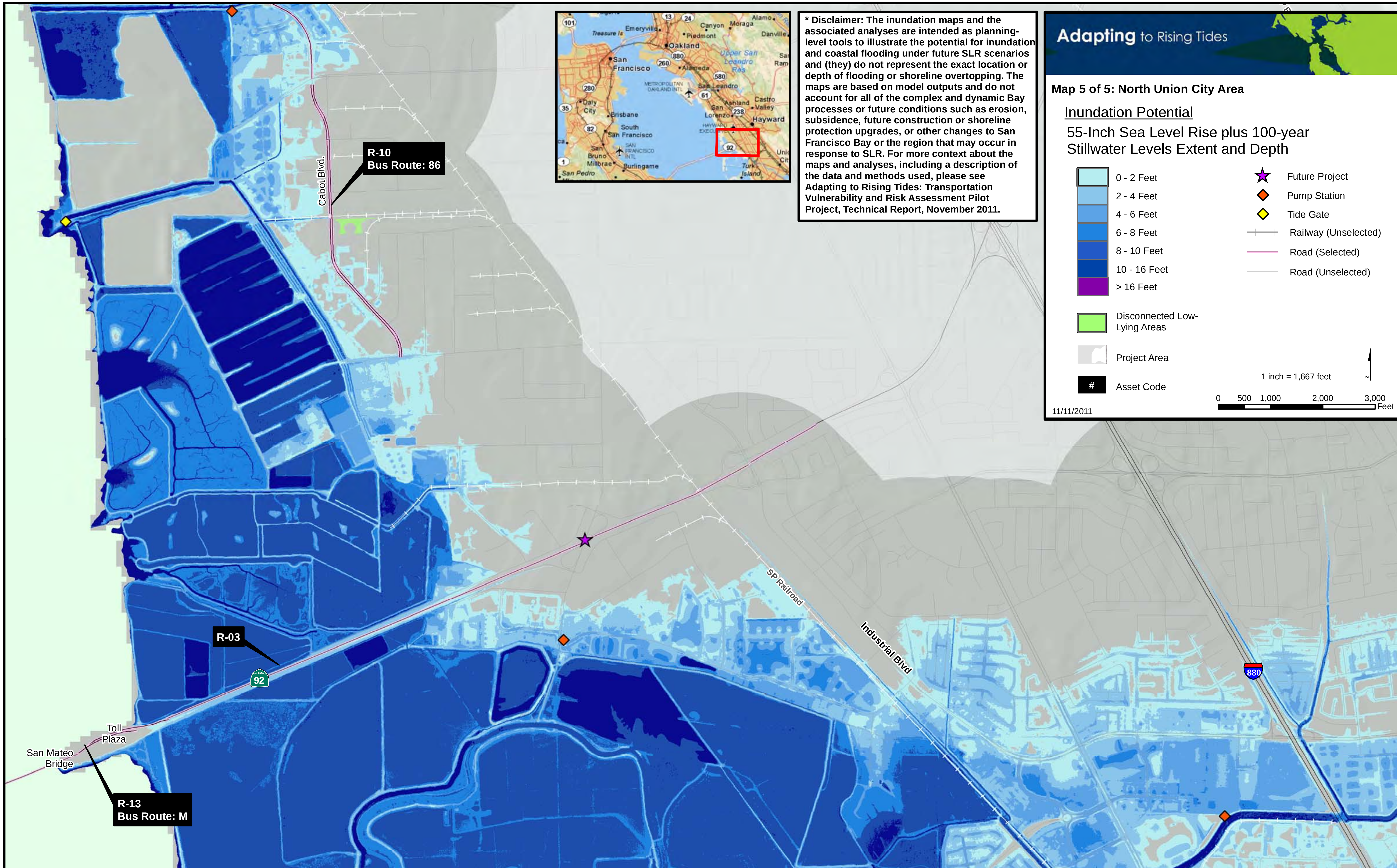


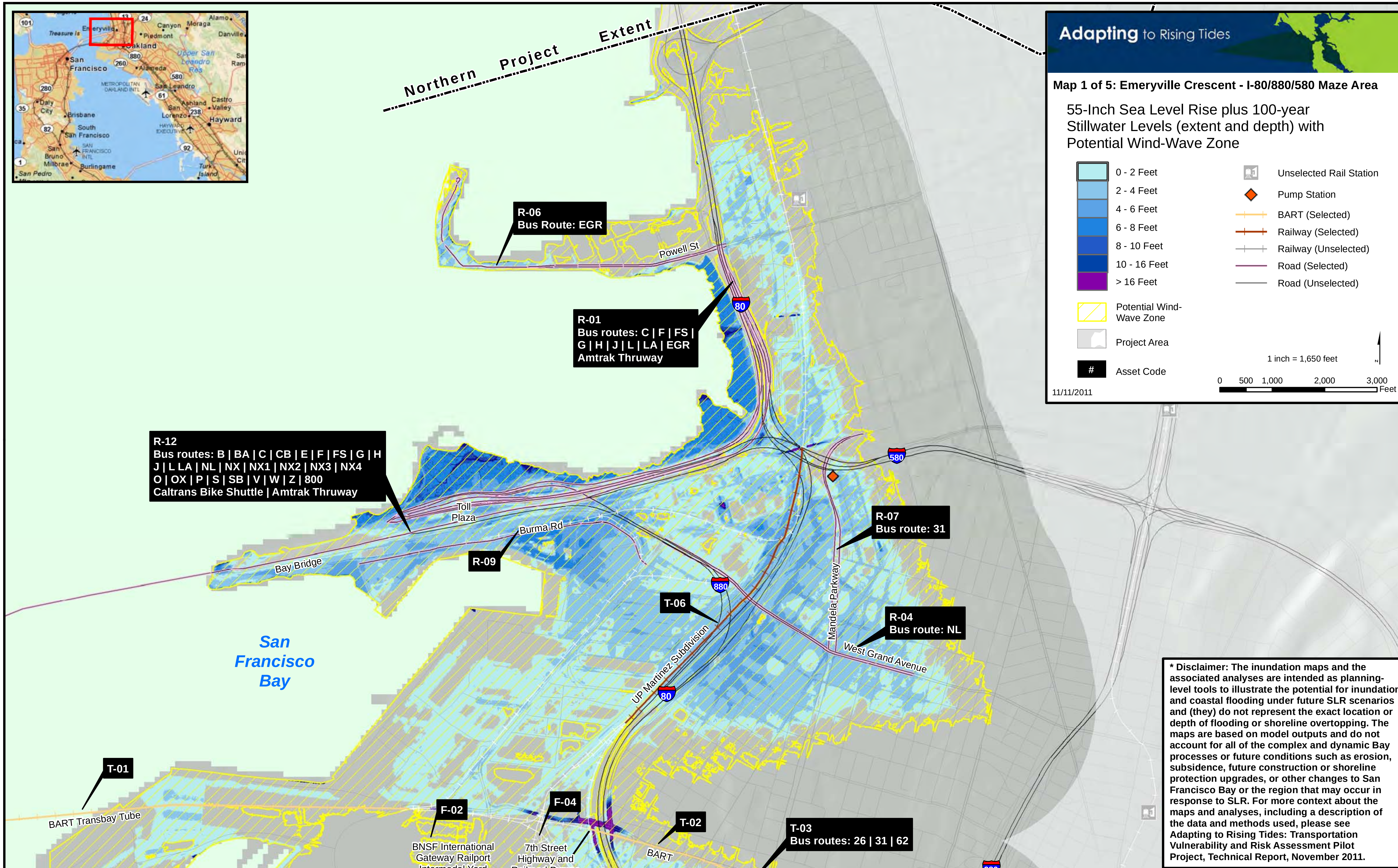
Adapting to Rising Tides
Map 1 of 5: Emeryville Crescent - I-80/880/580 Maze Area
Inundation Potential
55-Inch Sea Level Rise plus 100-year Stillwater Levels Extent and Depth
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Disconnected Low-Lying Areas
Project Area
Asset Code
Unselected Rail Station
Pump Station
BART (Selected)
Railway (Selected)
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 1,650 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
Northern Project Extent
R-06 Bus Route: EGR
Powell St
R-01 Bus routes: C | F | FS | G | H | J | L | LA | EGR Amtrak Thruway
R-12 Bus routes: 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
Toll Plaza
Burma Rd
Bay Bridge
R-09
R-07 Bus route: 31
Mandela Parkway
T-06
R-04 Bus route: NL
West Grand Avenue
UP Martinez Subdivision
San Francisco Bay
T-01
BART Transbay Tube
F-02
BNSF International Gateway Railport Intermodal Yard
F-04
7th Street Highway and Railroad Pumps
T-02
BART
T-03 Bus routes: 26 | 31 | 62
80
580
880
980
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.

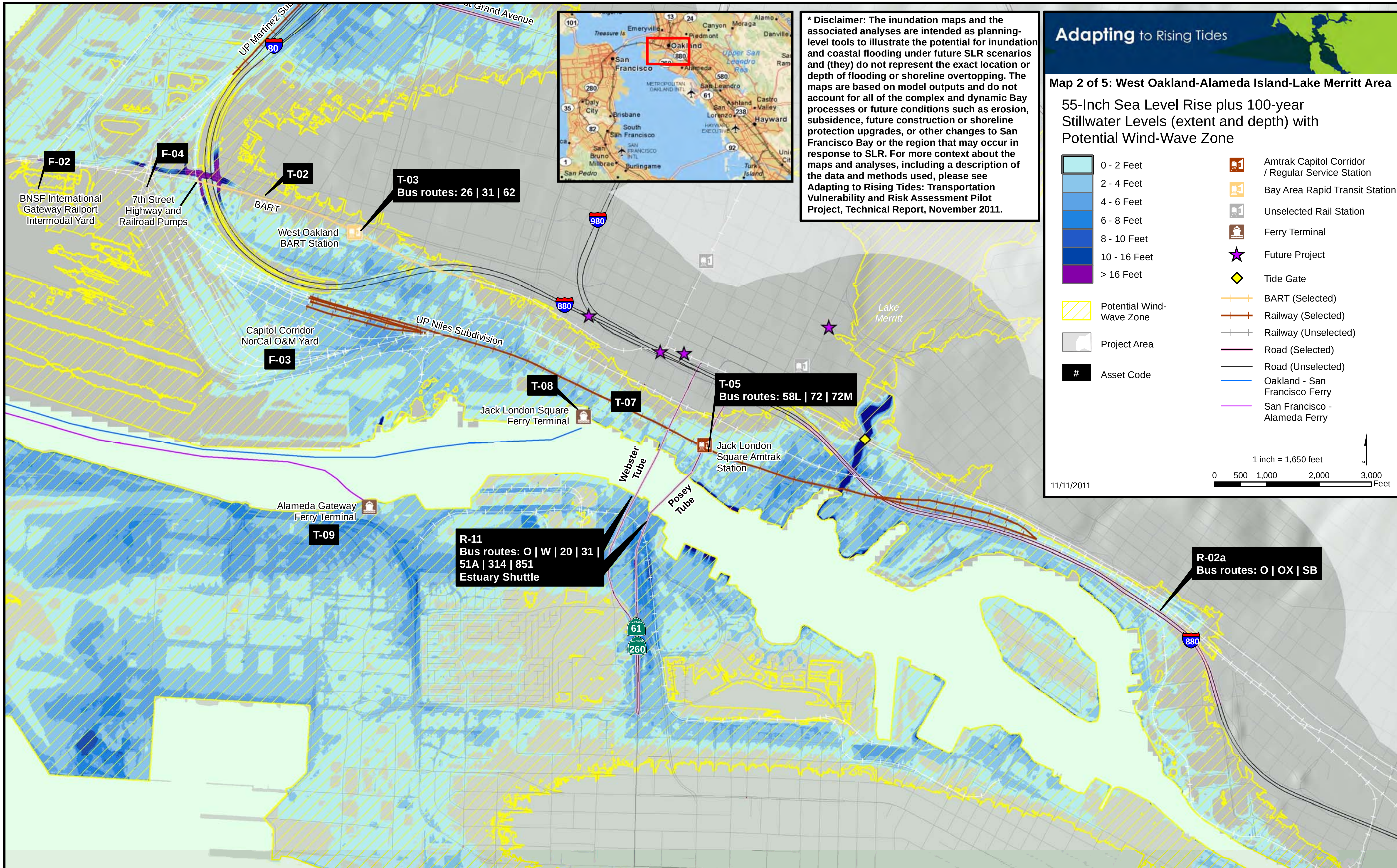

Adapting to Rising Tides
Map 2 of 5: West Oakland-Alameda Island-Lake Merritt Area
Inundation Potential
55-Inch Sea Level Rise plus 100-year Stillwater Levels Extent and Depth
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Disconnected Low-Lying Areas
Project Area
Asset Code
Amtrak Capitol Corridor / Regular Service Station
Bay Area Rapid Transit Station
Unselected Rail Station
Ferry Terminal
Future Project
Tide Gate
BART (Selected)
Railway (Selected)
Railway (Unselected)
Road (Selected)
Road (Unselected)
Oakland - San Francisco Ferry
San Francisco - Alameda Ferry
1 inch = 1,650 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
F-02
BNSF International Gateway Railport Intermodal Yard
F-04
7th Street Highway and Railroad Pumps
T-02
BART
T-03
Bus routes: 26 | 31 | 62
West Oakland BART Station
UP Martinez Sub
Grand Avenue
80
980
880
Capitol Corridor NorCal O&M Yard
F-03
UP Niles Subdivision
T-08
Jack London Square Ferry Terminal
T-07
T-05
Bus routes: 58L | 72 | 72M
Jack London Square Amtrak Station
Lake Merritt
Webster Tube
Posey Tube
Alameda Gateway Ferry Terminal
T-09
R-11
Bus routes: O | W | 20 | 31 | 51A | 314 | 851
Estuary Shuttle
61
260
R-02a
Bus routes: O | OX | SB

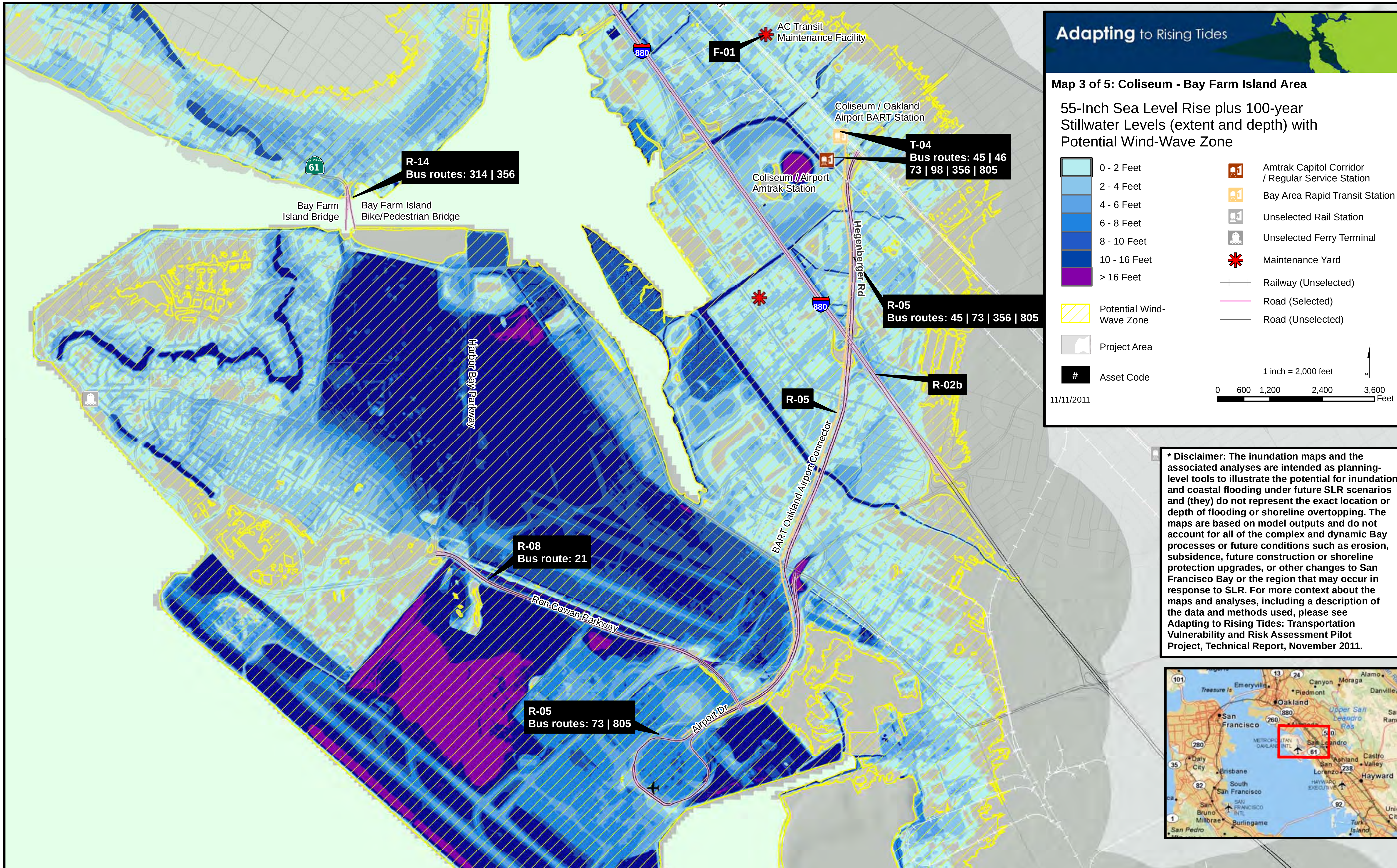

Adapting to Rising Tides
Map 3 of 5: Coliseum - Bay Farm Island Area
Inundation Potential
55-Inch Sea Level Rise plus 100-year Stillwater Levels Extent and Depth
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Disconnected Low-Lying Areas
Project Area
Asset Code
Amtrak Capitol Corridor / Regular Service Station
Bay Area Rapid Transit Station
Unselected Rail Station
Unselected Ferry Terminal
Maintenance Yard
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 2,000 feet
0 600 1,200 2,400 3,600 Feet
11/11/2011
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
F-01
AC Transit Maintenance Facility
Coliseum / Oakland Airport BART Station
T-04
Bus routes: 45 | 46 73 | 98 | 356 | 805
Coliseum / Airport Amtrak Station
R-14
Bus routes: 314 | 356
Bay Farm Island Bridge
Bay Farm Island Bike/Pedestrian Bridge
Hegenberger Rd
R-05
Bus routes: 45 | 73 | 356 | 805
R-02b
R-05
Harbor Bay Parkway
BART Oakland Airport Connector
R-08
Bus route: 21
Ron Cowan Parkway
R-05
Bus routes: 73 | 805
Airport Dr
880
61

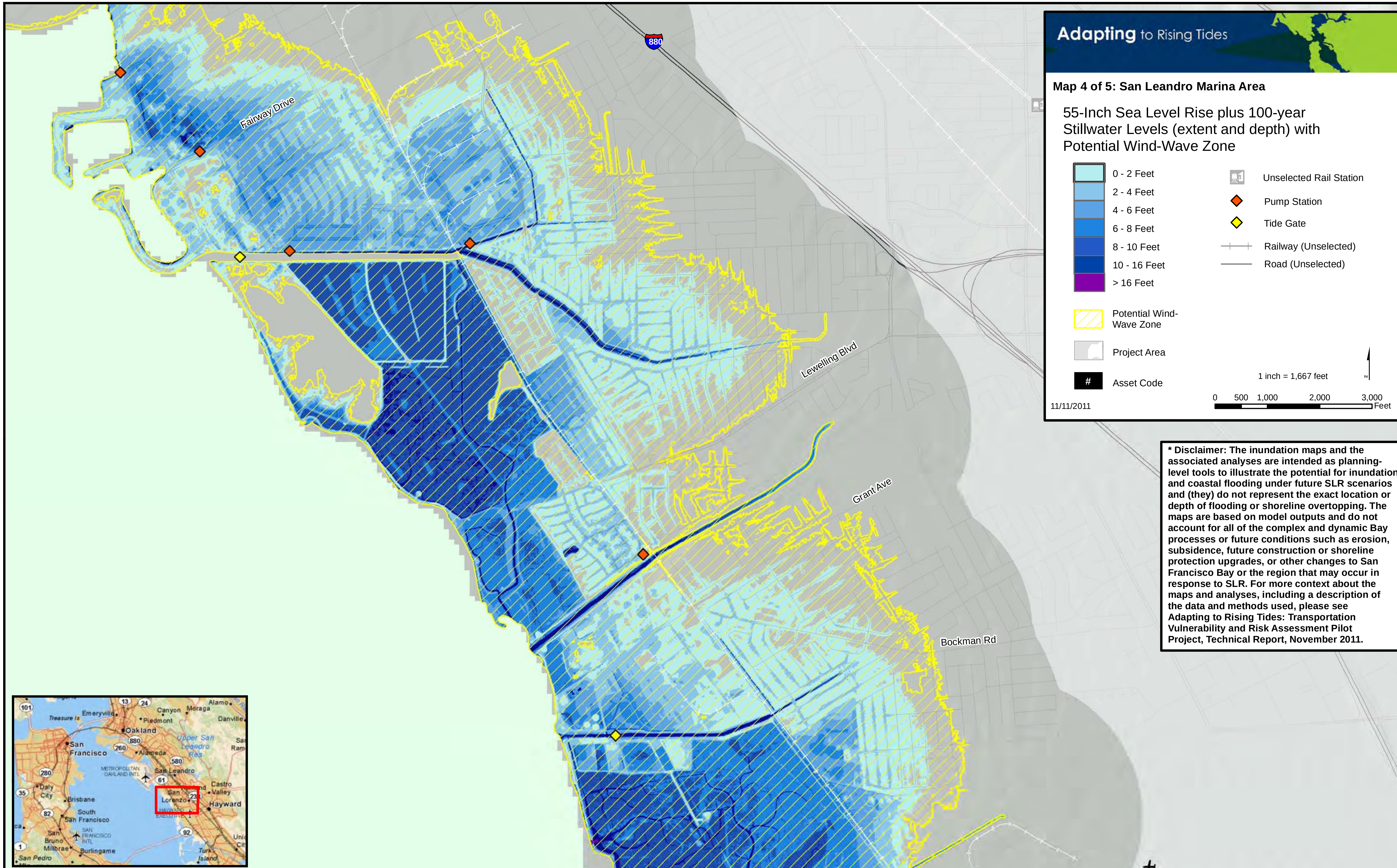

Adapting to Rising Tides
Map 4 of 5: San Leandro Marina Area
Inundation Potential
55-Inch Sea Level Rise plus 100-year Stillwater Levels Extent and Depth
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Disconnected Low-Lying Areas
Project Area
#
Asset Code
Unselected Rail Station
Pump Station
Tide Gate
Railway (Unselected)
Road (Unselected)
1 inch = 1,667 feet
0 500 1,000 2,000 3,000
Feet
11/11/2011
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
880
Fairway Drive
Lewelling Blvd
Grant Ave
Bockman Rd
Emeryville
Treasure Is
Oakland
Piedmont
Canyon
Moraga
Alamo
Danville
San Francisco
Alameda
San Leandro
San Lorenzo
Castro Valley
Hayward
Daly City
Brisbane
South San Francisco
San Bruno
Millbrae
Burlingame
San Pedro

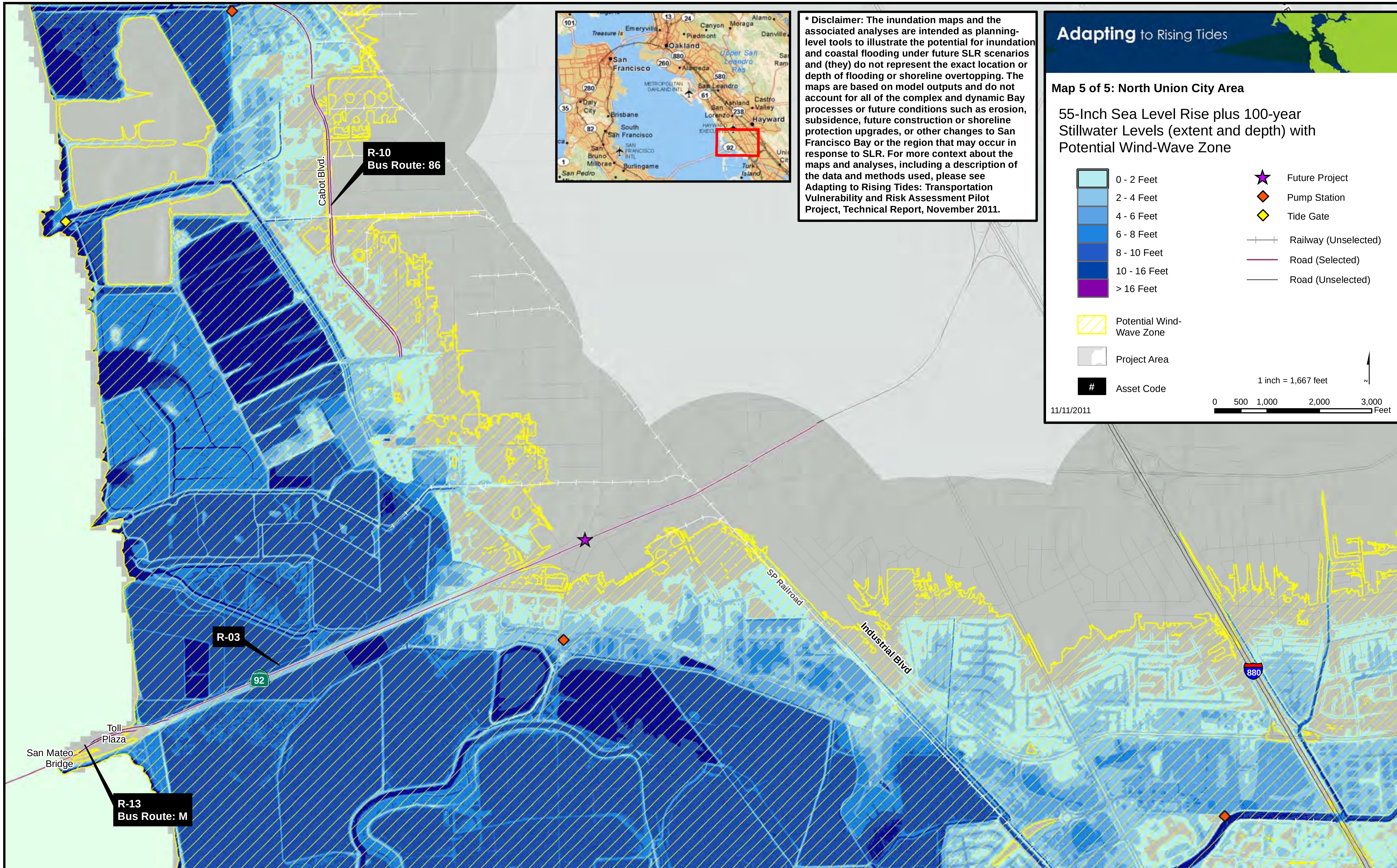

Adapting to Rising Tides
Map 5 of 5: North Union City Area
Inundation Potential
55-Inch Sea Level Rise plus 100-year Stillwater Levels Extent and Depth
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Disconnected Low-Lying Areas
Project Area
Asset Code
Future Project
Pump Station
Tide Gate
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 1,667 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
R-10
Bus Route: 86
Cabot Blvd.
R-03
92
Toll Plaza
San Mateo Bridge
R-13
Bus Route: M
SP Railroad
Industrial Blvd
880
San Francisco
Oakland
Emeryville
Piedmont
Alameda
San Leandro
Hayward
Castro Valley
Daly City
Brisbane
South San Francisco
San Bruno
Millbrae
Burlingame
Canyon
Moraga
Danville
San Lorenzo
Ashland
Treasure Is
Upper San Leandro Res
San Pedro


Adapting to Rising Tides
Map 1 of 5: Emeryville Crescent - I-80/880/580 Maze Area
55-Inch Sea Level Rise plus 100-year Stillwater Levels (extent and depth) with Potential Wind-Wave Zone
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Potential Wind-Wave Zone
Project Area
Asset Code
Unselected Rail Station
Pump Station
BART (Selected)
Railway (Selected)
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 1,650 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
Northern Project Extent
R-06
Bus Route: EGR
Powell St
R-01
Bus routes: C | F | FS | G | H | J | L | LA | EGR
Amtrak Thruway
R-12
Bus routes: 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
Toll Plaza
Burma Rd
R-09
Bay Bridge
R-07
Bus route: 31
T-06
Mandela Parkway
R-04
Bus route: NL
West Grand Avenue
UP Martinez Subdivision
San Francisco Bay
T-01
BART Transbay Tube
F-02
BNSF International Gateway Railport Intermodal Yard
F-04
7th Street Highway and Railroad Pumps
T-02
BART
T-03
Bus routes: 26 | 31 | 62
80
880
580
980
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.


Adapting to Rising Tides
Map 2 of 5: West Oakland-Alameda Island-Lake Merritt Area
55-Inch Sea Level Rise plus 100-year Stillwater Levels (extent and depth) with Potential Wind-Wave Zone
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Potential Wind-Wave Zone
Project Area
Asset Code
Amtrak Capitol Corridor / Regular Service Station
Bay Area Rapid Transit Station
Unselected Rail Station
Ferry Terminal
Future Project
Tide Gate
BART (Selected)
Railway (Selected)
Railway (Unselected)
Road (Selected)
Road (Unselected)
Oakland - San Francisco Ferry
San Francisco - Alameda Ferry
1 inch = 1,650 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
F-02
BNSF International Gateway Railport Intermodal Yard
F-04
7th Street Highway and Railroad Pumps
T-02
BART
T-03
Bus routes: 26 | 31 | 62
West Oakland BART Station
UP Martinez Sub
Grand Avenue
Capitol Corridor NorCal O&M Yard
F-03
UP Niles Subdivision
T-08
Jack London Square Ferry Terminal
T-07
T-05
Bus routes: 58L | 72 | 72M
Jack London Square Amtrak Station
Lake Merritt
Webster Tube
Posey Tube
Alameda Gateway Ferry Terminal
T-09
R-11
Bus routes: O | W | 20 | 31 | 51A | 314 | 851
Estuary Shuttle
R-02a
Bus routes: O | OX | SB
80
880
980
61
260


Adapting to Rising Tides
Map 3 of 5: Coliseum - Bay Farm Island Area
55-Inch Sea Level Rise plus 100-year Stillwater Levels (extent and depth) with Potential Wind-Wave Zone
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Potential Wind-Wave Zone
Project Area
Asset Code
Amtrak Capitol Corridor / Regular Service Station
Bay Area Rapid Transit Station
Unselected Rail Station
Unselected Ferry Terminal
Maintenance Yard
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 2,000 feet
0 600 1,200 2,400 3,600 Feet
11/11/2011
F-01
AC Transit Maintenance Facility
Coliseum / Oakland Airport BART Station
T-04
Bus routes: 45 | 46 73 | 98 | 356 | 805
Coliseum / Airport Amtrak Station
R-14
Bus routes: 314 | 356
Bay Farm Island Bridge
Bay Farm Island Bike/Pedestrian Bridge
Hegenberger Rd
R-05
Bus routes: 45 | 73 | 356 | 805
R-02b
R-05
Harbor Bay Parkway
BART Oakland Airport Connector
R-08
Bus route: 21
Ron Cowan Parkway
R-05
Bus routes: 73 | 805
Airport Dr
880
61
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.


Adapting to Rising Tides
Map 4 of 5: San Leandro Marina Area
55-Inch Sea Level Rise plus 100-year Stillwater Levels (extent and depth) with Potential Wind-Wave Zone
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Potential Wind-Wave Zone
Project Area
Asset Code
Unselected Rail Station
Pump Station
Tide Gate
Railway (Unselected)
Road (Unselected)
1 inch = 1,667 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
Fairway Drive
880
Lewelling Blvd
Grant Ave
Bockman Rd
Oakland
San Francisco
Alameda
San Leandro
San Lorenzo
Hayward
Castro Valley
Daly City
Brisbane
South San Francisco
Burlingame
Emeryville
Piedmont
Moraga
Danville


Adapting to Rising Tides
Map 5 of 5: North Union City Area
55-Inch Sea Level Rise plus 100-year Stillwater Levels (extent and depth) with Potential Wind-Wave Zone
0 - 2 Feet
2 - 4 Feet
4 - 6 Feet
6 - 8 Feet
8 - 10 Feet
10 - 16 Feet
> 16 Feet
Potential Wind-Wave Zone
Project Area
#
Asset Code
Future Project
Pump Station
Tide Gate
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 1,667 feet
0 500 1,000 2,000 3,000
Feet
11/11/2011
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
R-10
Bus Route: 86
Cabot Blvd.
R-03
92
Toll Plaza
San Mateo Bridge
R-13
Bus Route: M
SP Railroad
Industrial Blvd
880
San Francisco
Oakland
Emeryville
Piedmont
Alameda
San Leandro
Hayward
Daly City
Brisbane
South San Francisco
San Bruno
Millbrae
Burlingame
San Lorenzo
Castro Valley
Ashland
Moraga
Canyon
Danville
Alamo
Treasure Is
Upper San Leandro Res
San Pedro
Turk Island

MAPS SHOWING DEPTHS OF SHORELINE SYSTEMS OVERTOPPED

16" MHHW, MHHW + 100-yr SWEL, MHHW + 100-yr SWEL + wind waves (1)

55" MHHW, MHHW + 100-yr SWEL, MHHW + 100-yr SWEL + wind waves (1)

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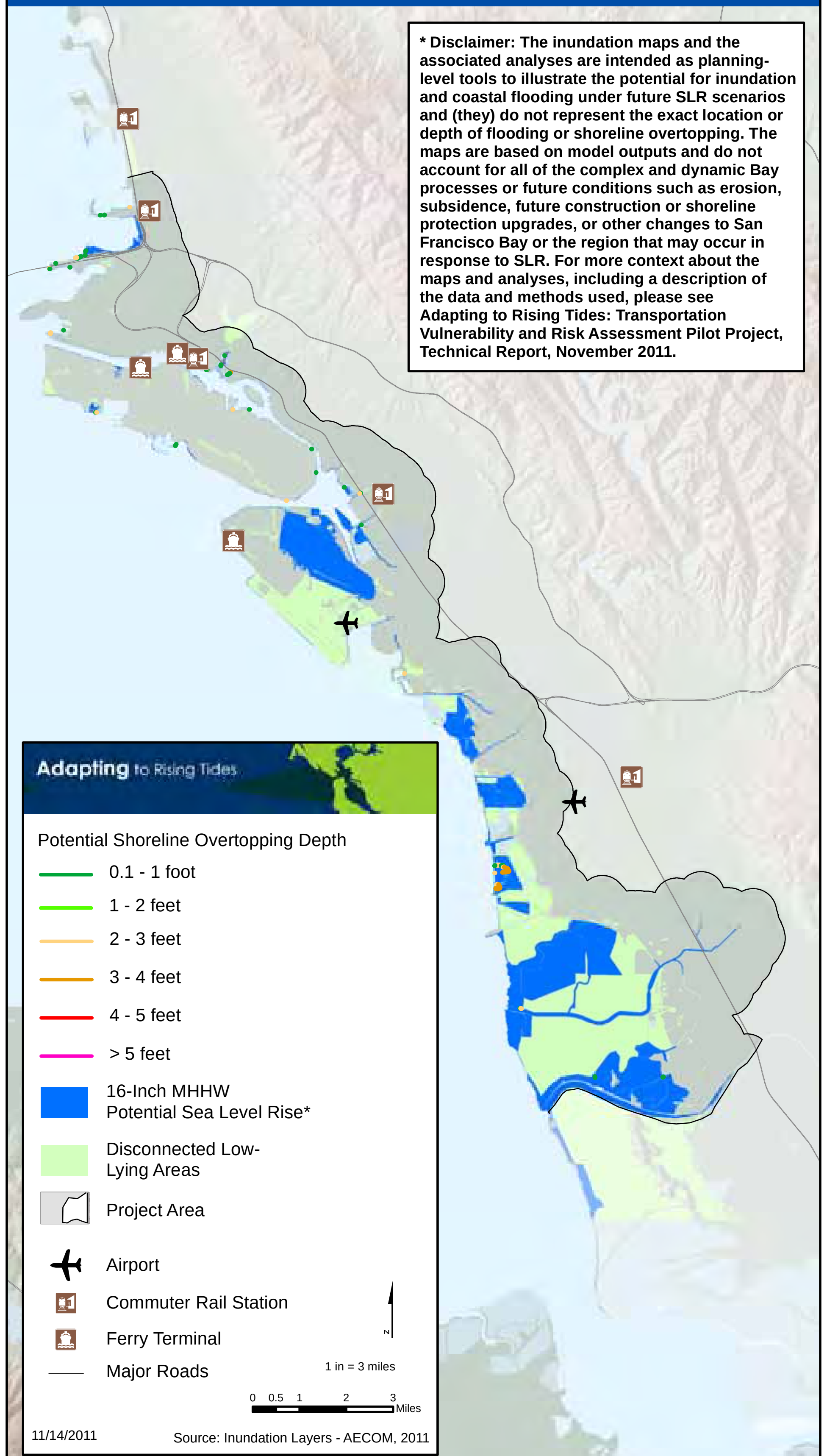
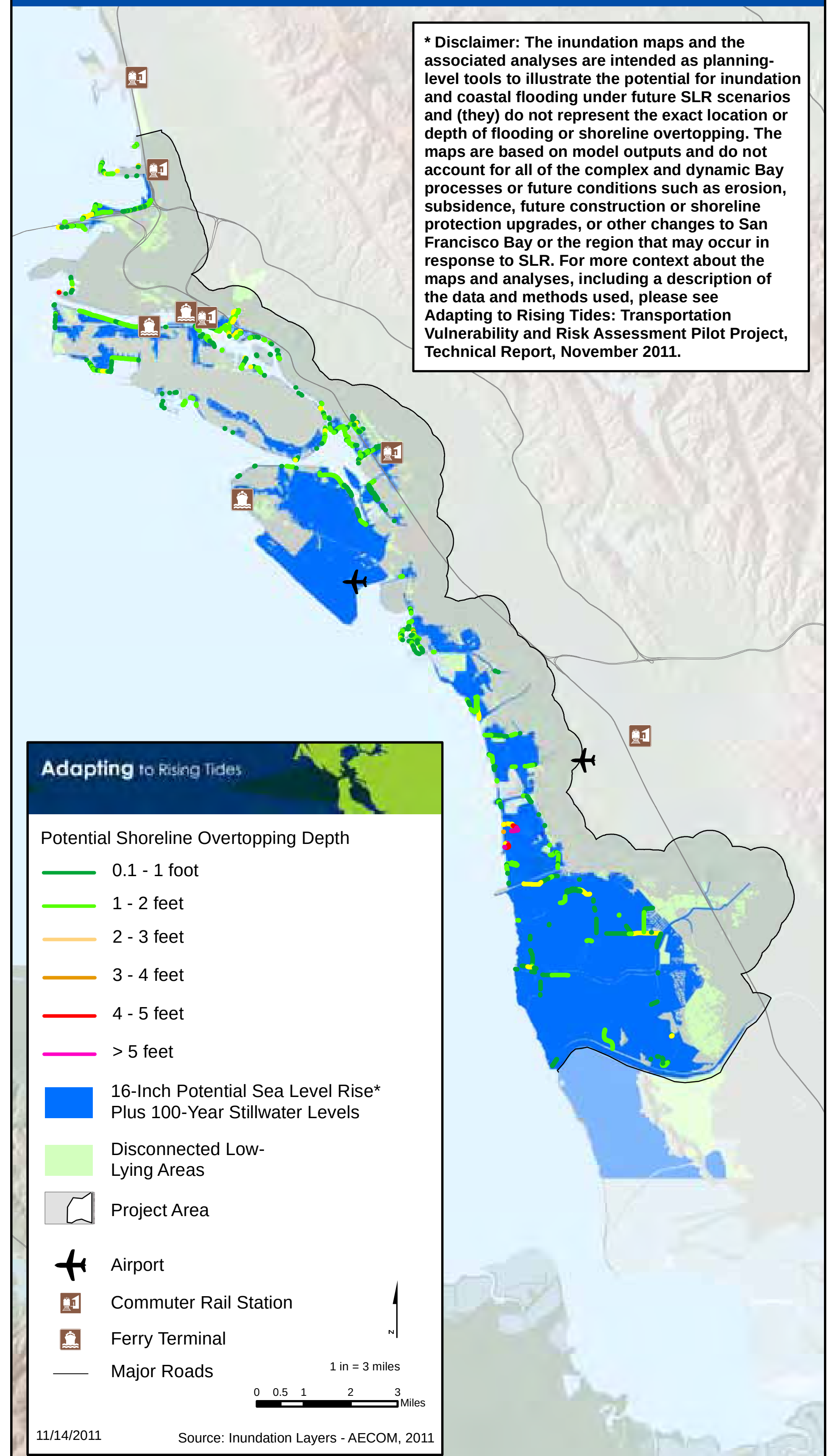
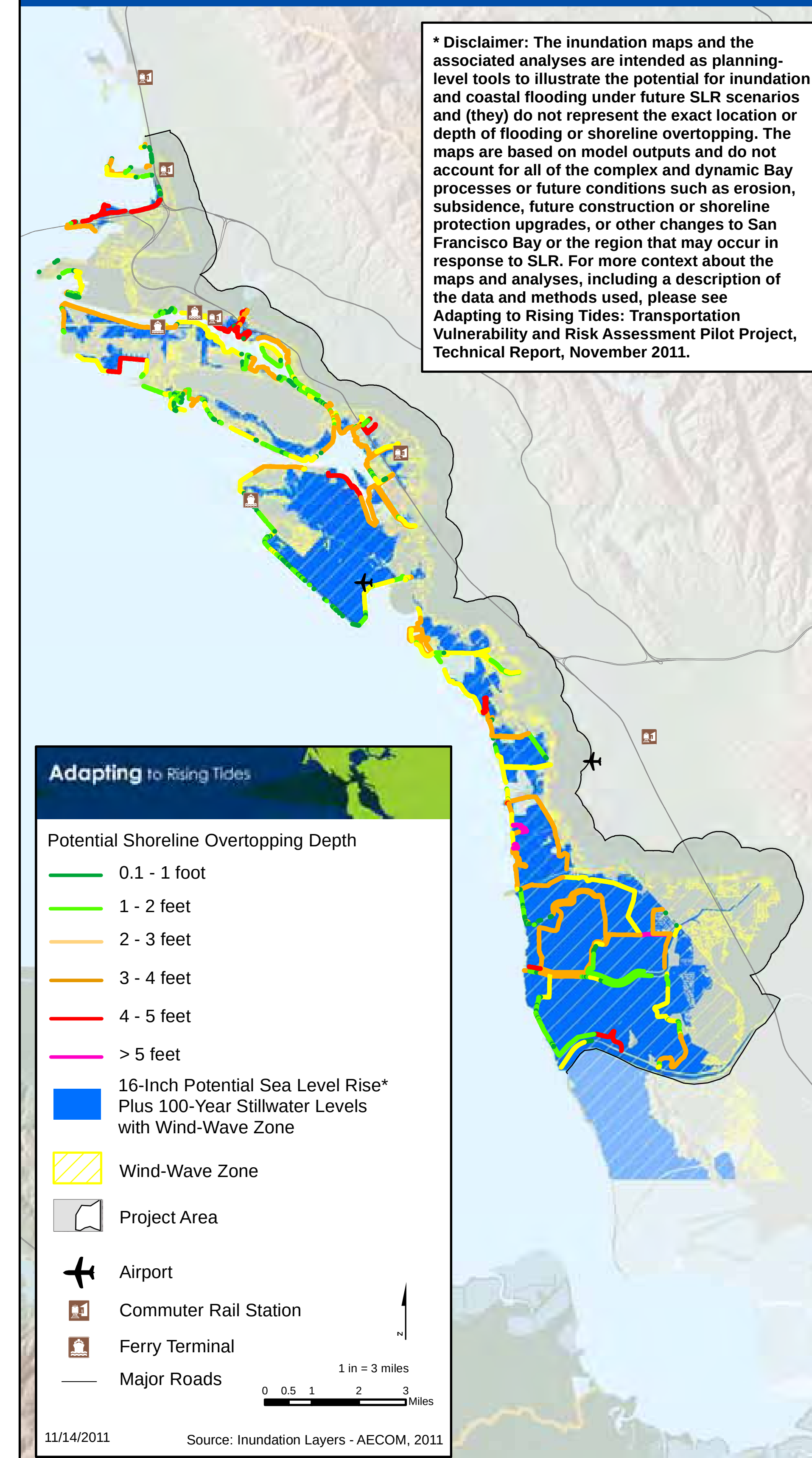
16-Inch MHHW Potential Sea Level Rise with Potential Shoreline Overtopping Depth



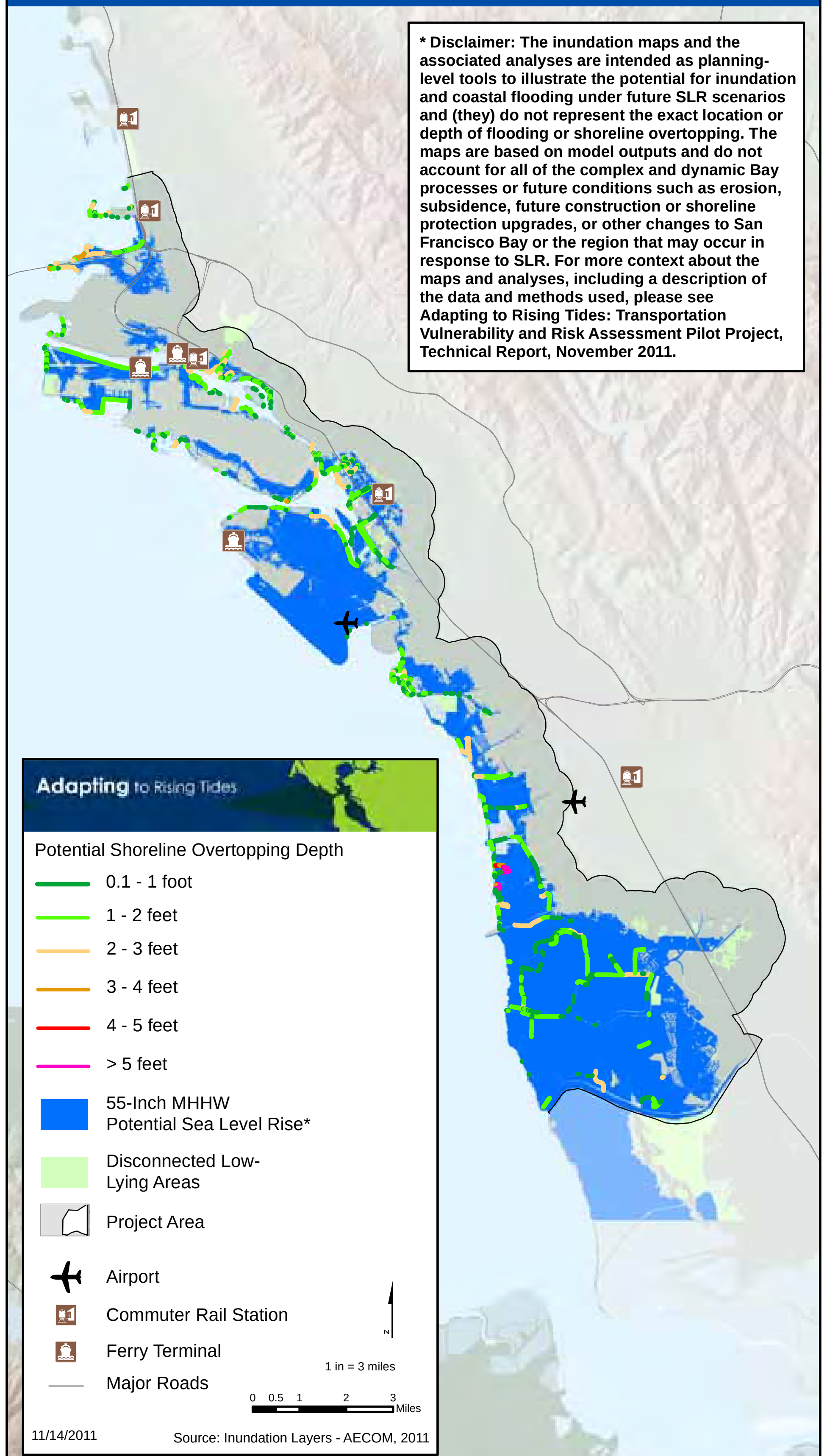
16-Inch Potential Sea Level Rise plus 100-Year Stillwater Levels with Potential Shoreline Overtopping Depth



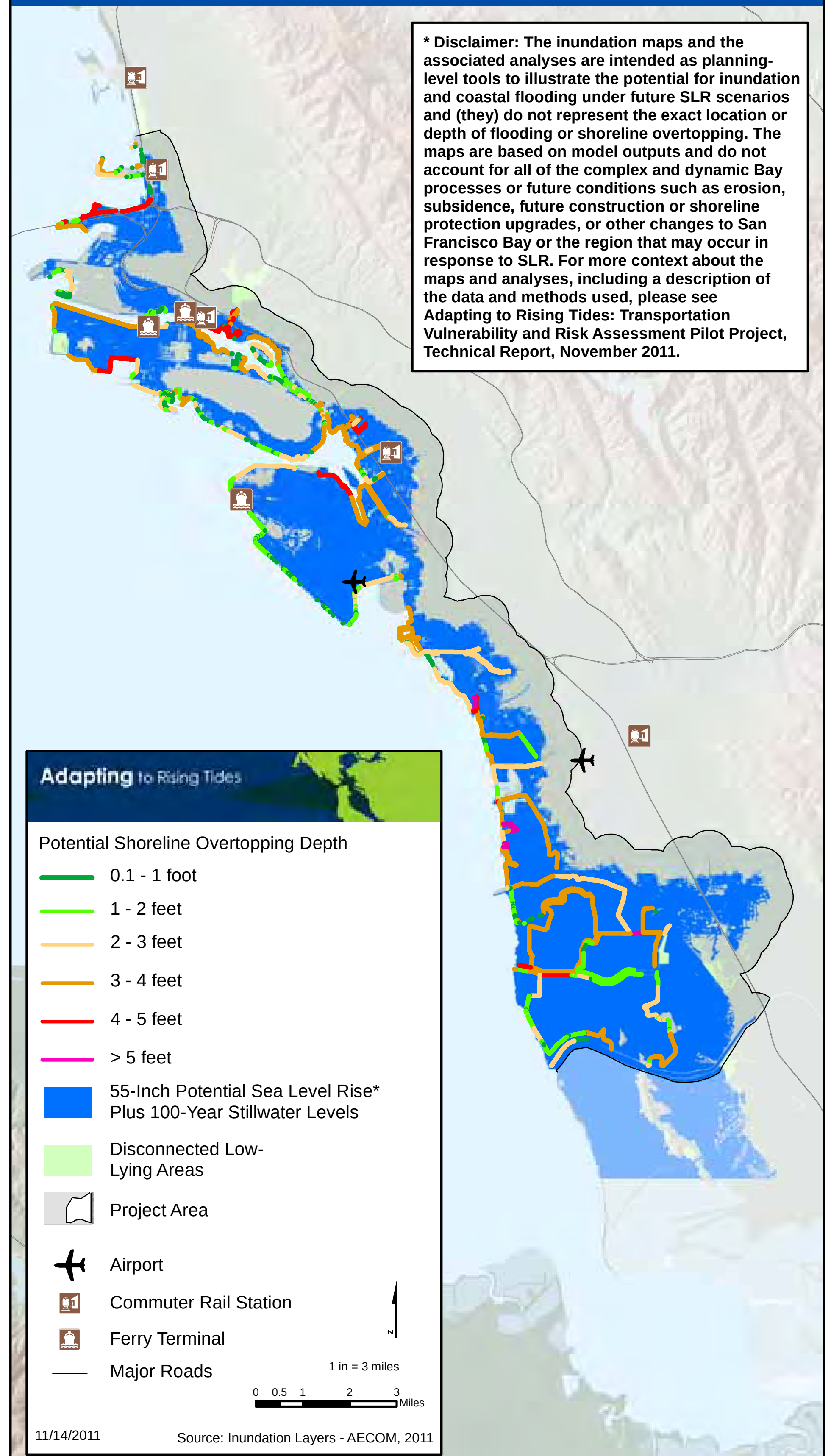
16-Inch Potential Sea Level Rise plus 100-Year Stillwater Levels With Wind-Wave Zone with Potential Shoreline Overtopping Depth



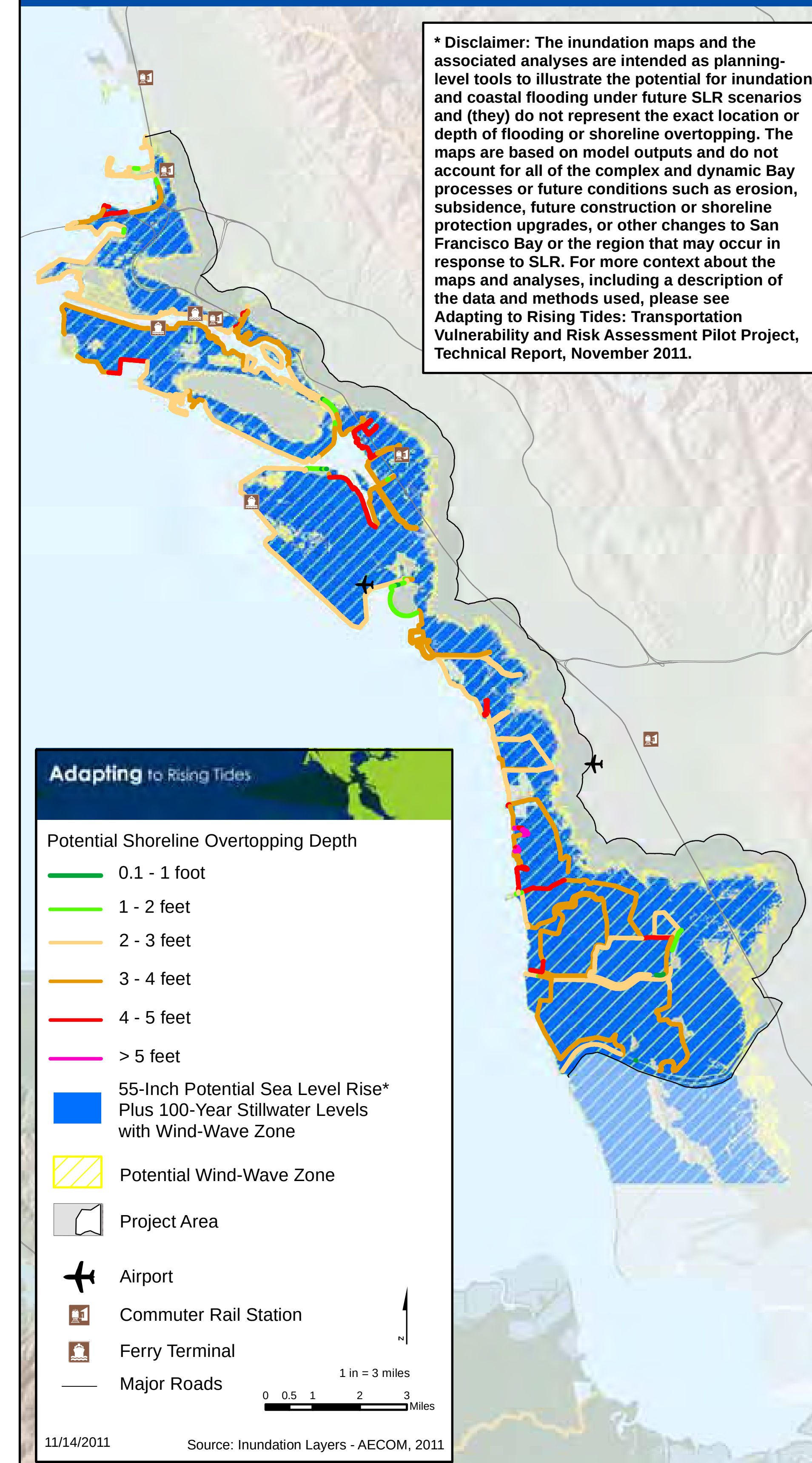
55-Inch MHHW Potential Sea Level Rise with Potential Shoreline Overtopping Depth



55-Inch Potential Sea Level Rise plus 100-Year Stillwater Levels with Potential Shoreline Overtopping Depth



55-Inch Potential Sea Level Rise plus 100-Year Stillwater Levels With Wind-Wave Zone with Potential Shoreline Overtopping Depth



MAPS SHOWING PERCENTAGES OF SHORELINE SYSTEMS OVERTOPPED

16" MHHW, MHHW + 100-yr SWEL, MHHW + 100-yr SWEL + wind waves (1)

55" MHHW, MHHW + 100-yr SWEL, MHHW + 100-yr SWEL + wind waves (1)

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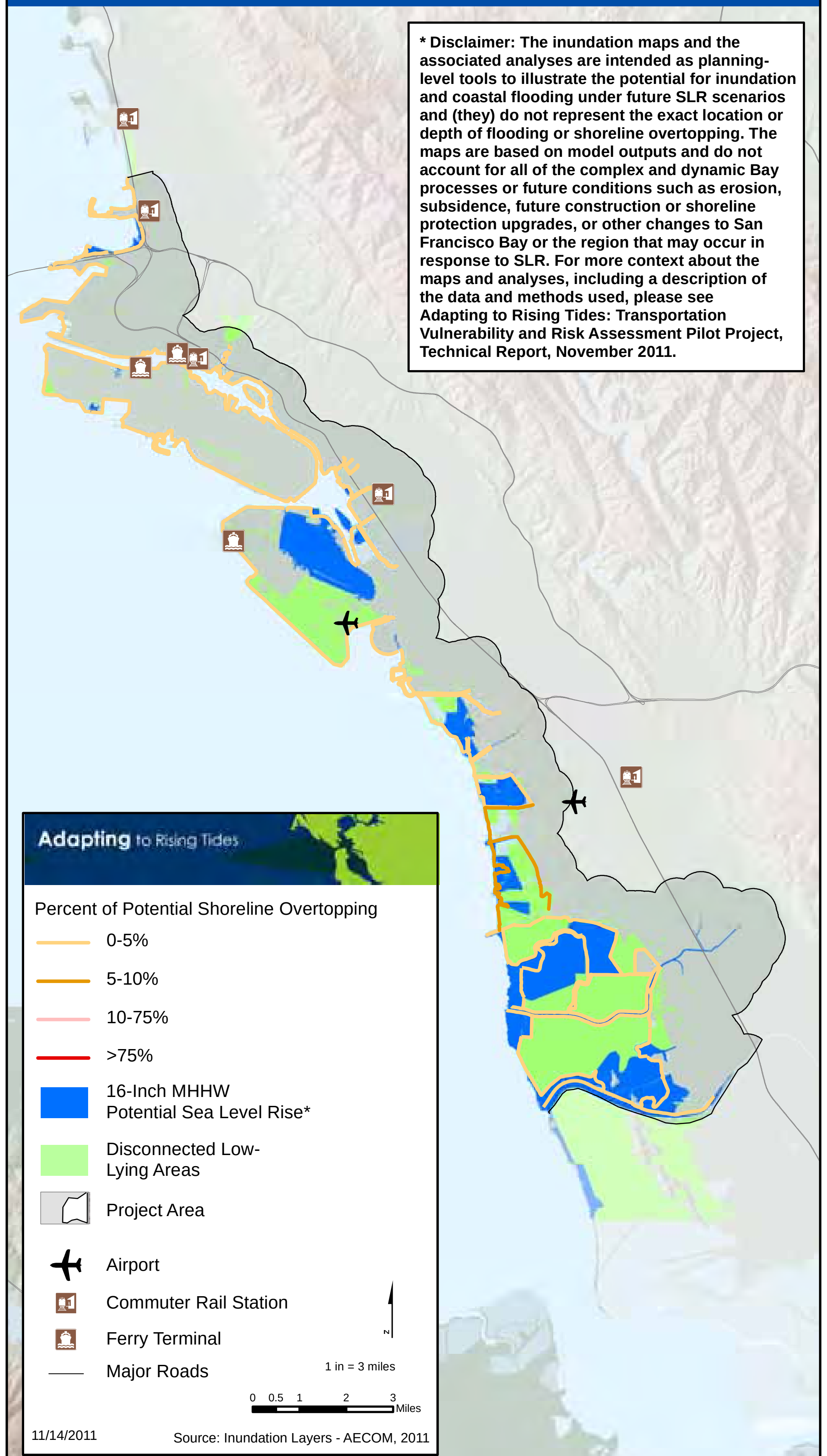
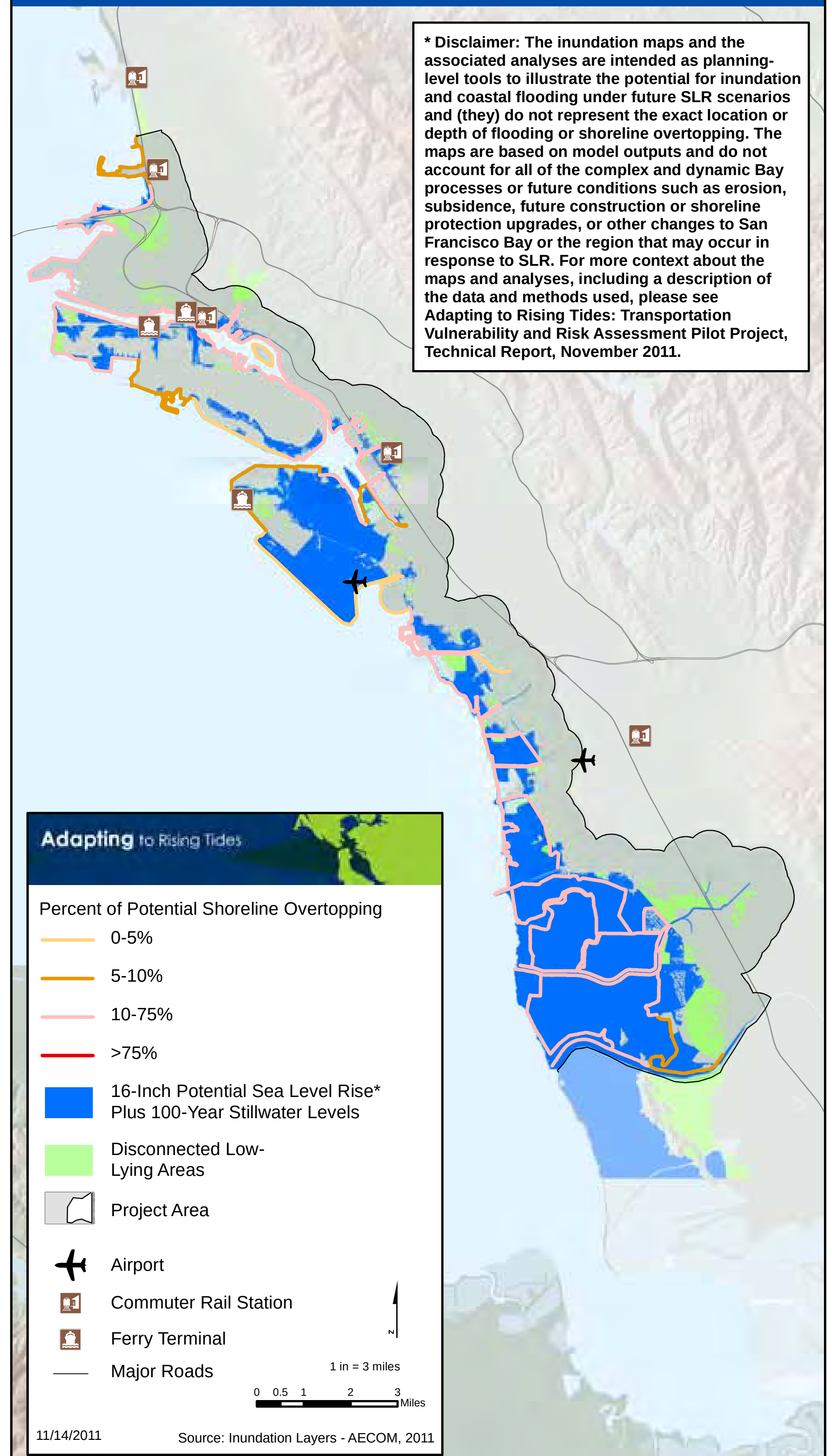
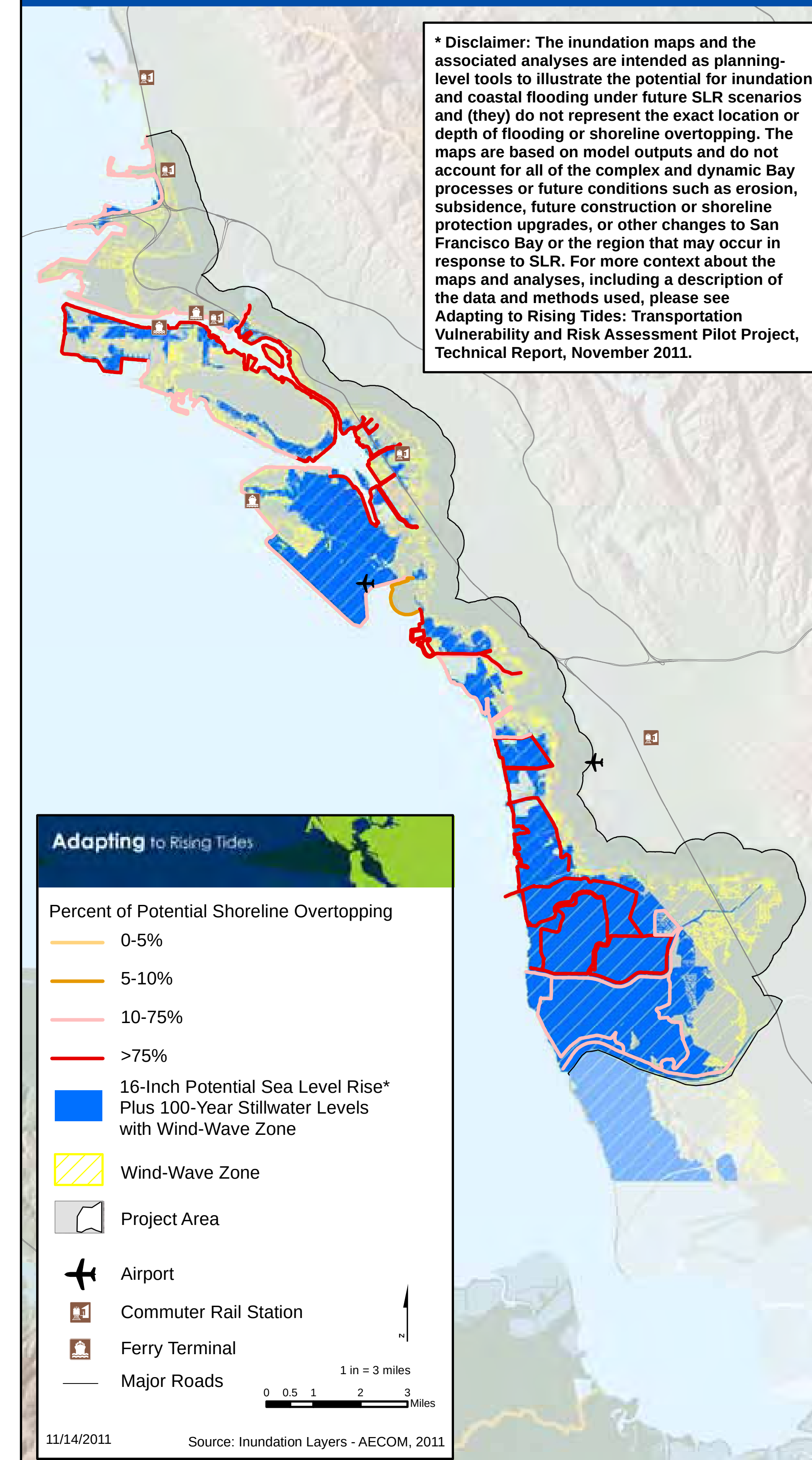
16-Inch MHHW Potential Sea Level Rise with Potential Shoreline Overtopping Percentages



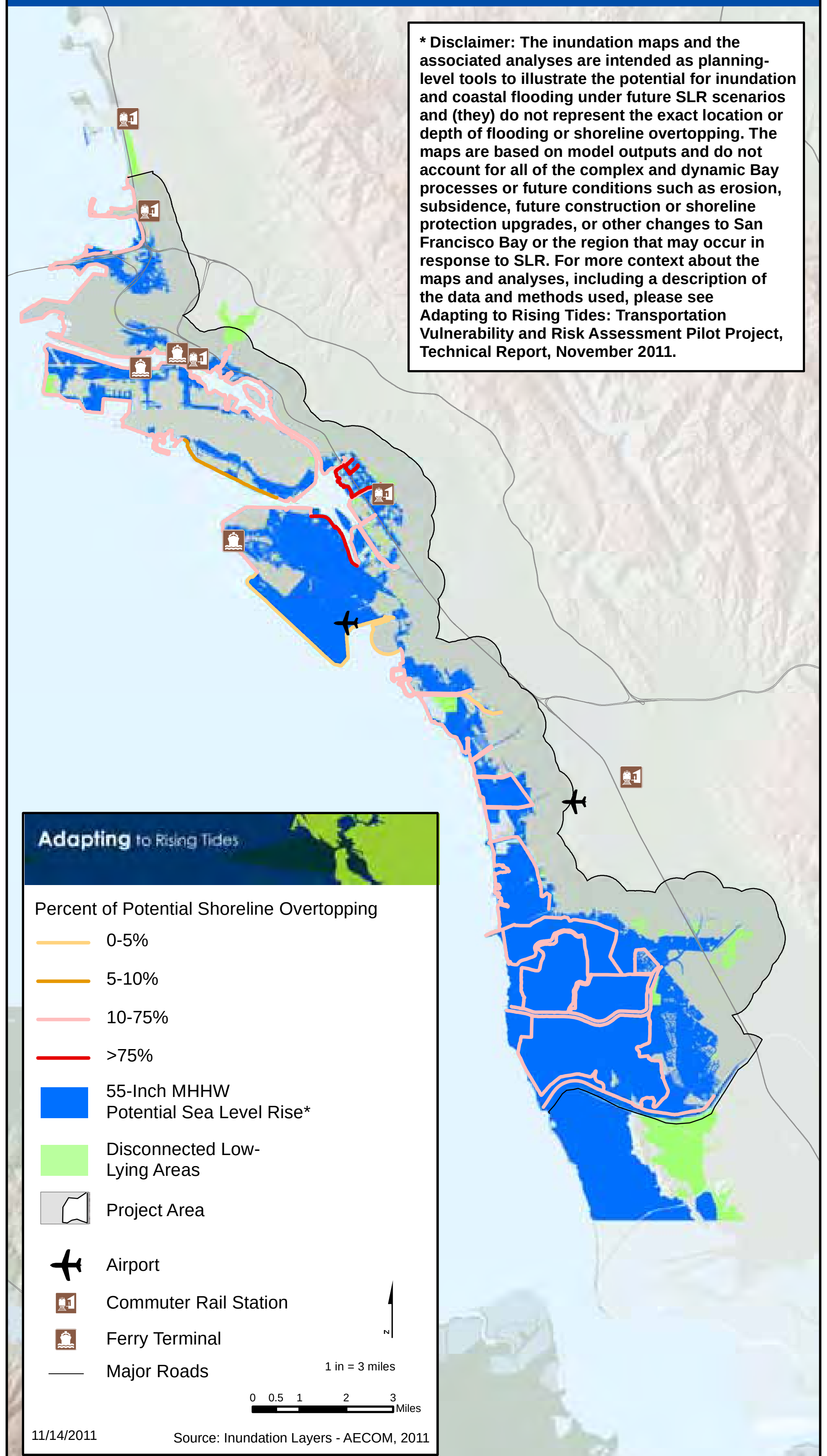
16-Inch Potential Sea Level Rise plus 100-Year Stillwater Levels with Potential Shoreline Overtopping Percentages



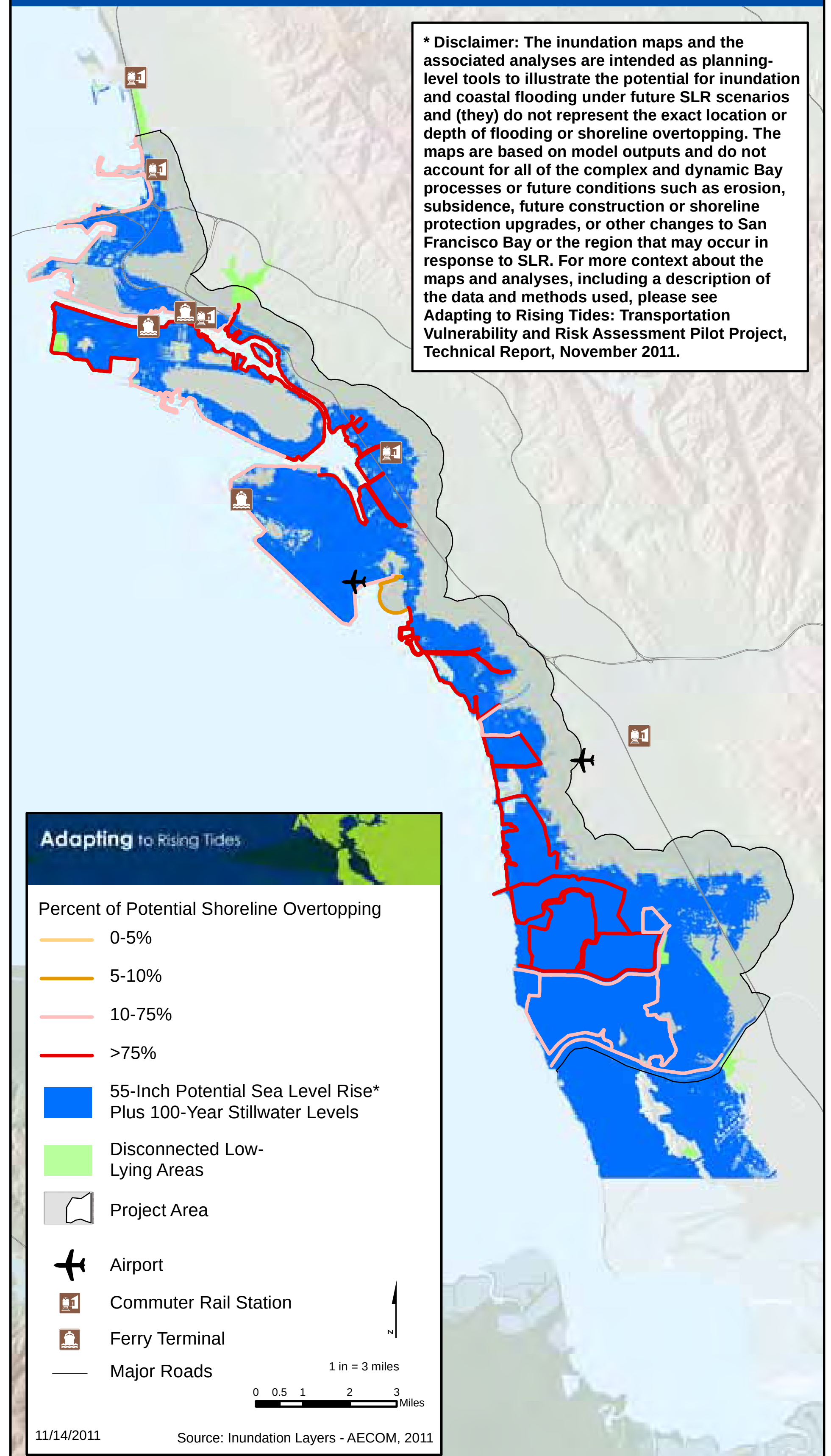
16-Inch Potential Sea Level Rise plus 100-Year Stillwater Levels With Wind-Wave Zone with Potential Shoreline Overtopping Percentages



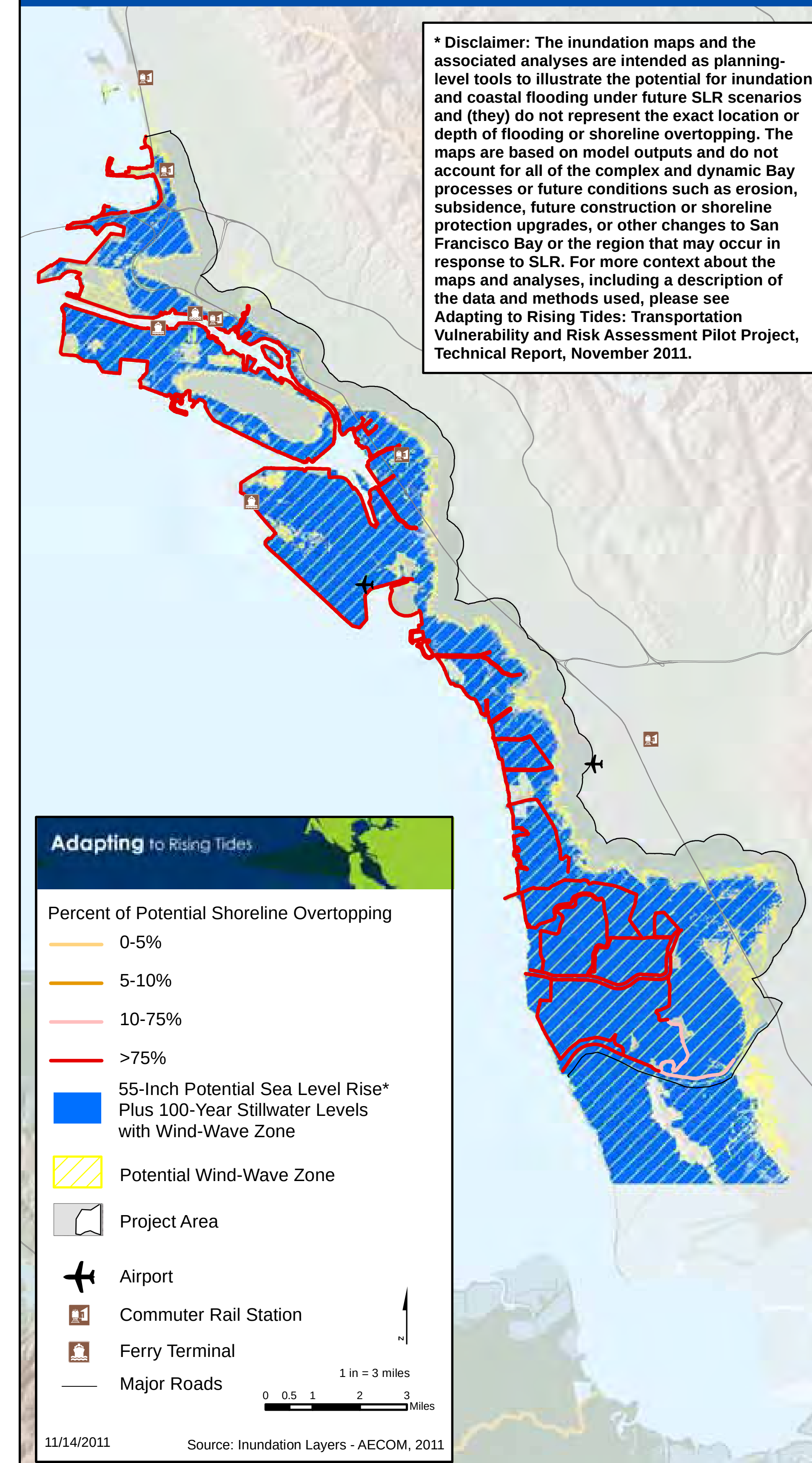
55-Inch MHHW Potential Sea Level Rise with Potential Shoreline Overtopping Percentage



55-Inch Potential Sea Level Rise plus 100-Year Stillwater Levels with Potential Shoreline Overtopping Percentage



55-Inch Potential Sea Level Rise plus 100-Year Stillwater Levels With Wind-Wave Zone with Potential Shoreline Overtopping Percentage



OVERTOPPING DEPTH ZOOM-IN MAPS SHOWING THE SELECTED TRANSPORTATION ASSET LOCATIONS

16" MHHW + 100-yr SWEL (5)

55" MHHW + 100-yr SWEL (5)

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Adapting to Rising Tides
Map 1 of 5: Emeryville Crescent - I-80/880/580 Maze Area
Shoreline Overtopping Potential
16-Inch Sea Level Rise plus 100-year Stillwater Levels Overtopping Depth Along Shoreline Feature
0.1 - 1 foot
1 - 2 feet
2 - 3 feet
3 - 4 feet
4 - 5 feet
> 5 feet
Shoreline System
Shoreline System Boundary
Shoreline System Number
Asset Code
Project Area
Unselected Rail Station
Pump Station
BART (Selected)
Railway (Selected)
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 1,650 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
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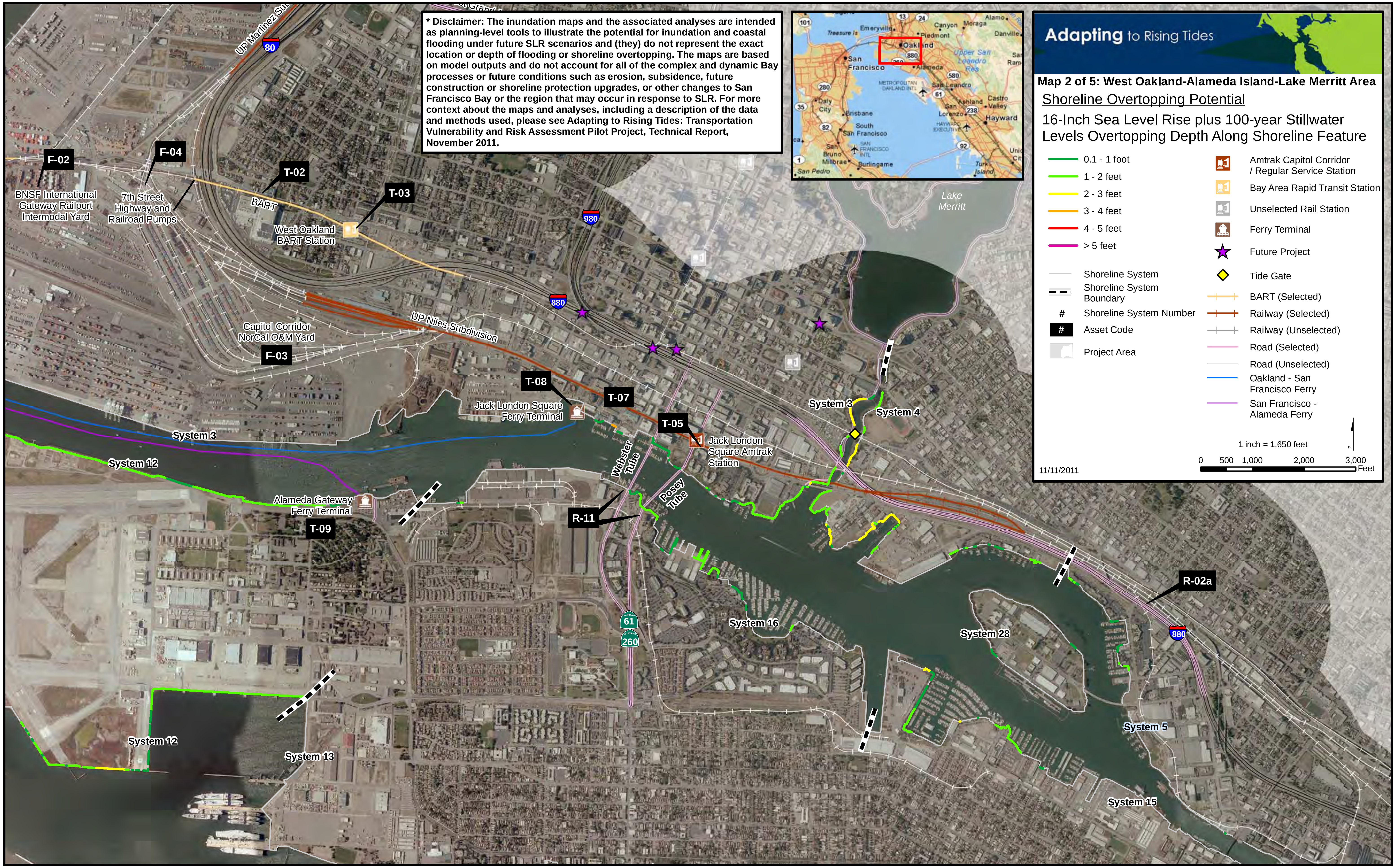
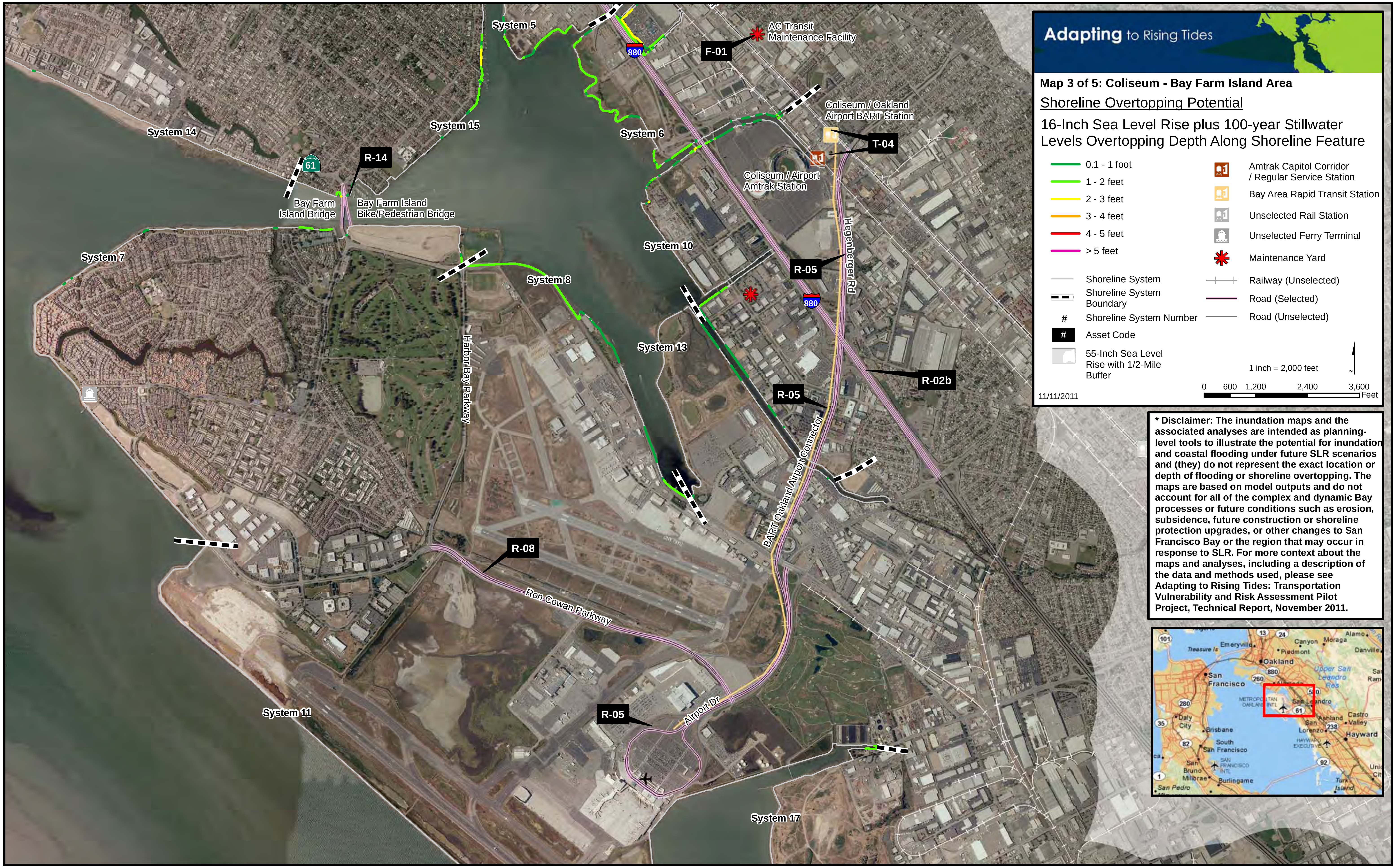
Northern Project Extent
System 1
System 2
System 3
R-06
R-01
R-12
R-09
R-07
R-04
T-06
T-01
T-02
T-03
F-02
F-04
Powell St
Toll Plaza
Burma Rd
Bay Bridge
Mandela Parkway
West Grand Avenue
UP Martinez Subdivision
BART Transbay Tube
BART
BNSF International Gateway Railport Intermodal Yard
7th Street Highway and Railroad Pumps
San Francisco Bay
Lake Merritt
80
580
880
980
Treasure Is
Emeryville
Piedmont
Oakland
San Francisco
Alameda
San Leandro
Daly City
Brisbane
South San Francisco
San Bruno
Millbrae
Burlingame
San Pedro
Hayward
Castro Valley
San Lorenzo
Ashland
Canyon
Moraga
Alamo
Danville
Upper San Leandro Res


Adapting to Rising Tides
Map 2 of 5: West Oakland-Alameda Island-Lake Merritt Area
Shoreline Overtopping Potential
16-Inch Sea Level Rise plus 100-year Stillwater Levels Overtopping Depth Along Shoreline Feature
0.1 - 1 foot
1 - 2 feet
2 - 3 feet
3 - 4 feet
4 - 5 feet
> 5 feet
Shoreline System
Shoreline System Boundary
Shoreline System Number
Asset Code
Project Area
Amtrak Capitol Corridor / Regular Service Station
Bay Area Rapid Transit Station
Unselected Rail Station
Ferry Terminal
Future Project
Tide Gate
BART (Selected)
Railway (Selected)
Railway (Unselected)
Road (Selected)
Road (Unselected)
Oakland - San Francisco Ferry
San Francisco - Alameda Ferry
1 inch = 1,650 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and (they) do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model outputs and do not account for all of the complex and dynamic Bay processes or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, or other changes to San Francisco Bay or the region that may occur in response to SLR. For more context about the maps and analyses, including a description of the data and methods used, please see Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, Technical Report, November 2011.
F-02
BNSF International Gateway Railport Intermodal Yard
F-04
7th Street Highway and Railroad Pumps
T-02
BART
T-03
West Oakland BART Station
UP Martinez Sub
80
980
880
UP Niles Subdivision
Capitol Corridor NorCal O&M Yard
F-03
T-08
Jack London Square Ferry Terminal
T-07
T-05
Jack London Square Amtrak Station
Lake Merritt
System 3
System 4
System 12
Webster Tube
Posey Tube
Alameda Gateway Ferry Terminal
T-09
R-11
R-02a
System 16
System 28
61
260
System 5
System 13
System 15
Oakland
San Francisco
Alameda
Emeryville
Piedmont
San Leandro
Hayward
Daly City
Brisbane
South San Francisco
San Bruno
Millbrae
Burlingame
Castro Valley
Treasure Is
Canyon
Moraga
Danville
San Lorenzo
Ashland
San Pedro
Upper San Leandro Res
Metropolitan Oakland Intl
San Francisco Intl
Hayward Executive


Adapting to Rising Tides
Map 3 of 5: Coliseum - Bay Farm Island Area
Shoreline Overtopping Potential
16-Inch Sea Level Rise plus 100-year Stillwater Levels Overtopping Depth Along Shoreline Feature
0.1 - 1 foot
1 - 2 feet
2 - 3 feet
3 - 4 feet
4 - 5 feet
> 5 feet
Shoreline System
Shoreline System Boundary
Shoreline System Number
Asset Code
55-Inch Sea Level Rise with 1/2-Mile Buffer
Amtrak Capitol Corridor / Regular Service Station
Bay Area Rapid Transit Station
Unselected Rail Station
Unselected Ferry Terminal
Maintenance Yard
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 2,000 feet
0 600 1,200 2,400 3,600 Feet
11/11/2011
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System 5
System 6
System 7
System 8
System 10
System 11
System 13
System 14
System 15
System 17
AC Transit Maintenance Facility
F-01
Coliseum / Oakland Airport BART Station
T-04
Coliseum / Airport Amtrak Station
R-14
R-05
R-02b
R-08
Bay Farm Island Bridge
Bay Farm Island Bike/Pedestrian Bridge
Harbor Bay Parkway
Hegenberger Rd
BART Oakland Airport Connector
Ron Cowan Parkway
Airport Dr
880
61
Oakland
San Francisco
Emeryville
Piedmont
Treasure Is
Canyon
Moraga
Alamo
Danville
Upper San Leandro Res
San Leandro
San Lorenzo
Ashland
Castro Valley
Hayward
Daly City
Brisbane
South San Francisco
San Bruno
Millbrae
Burlingame
San Pedro

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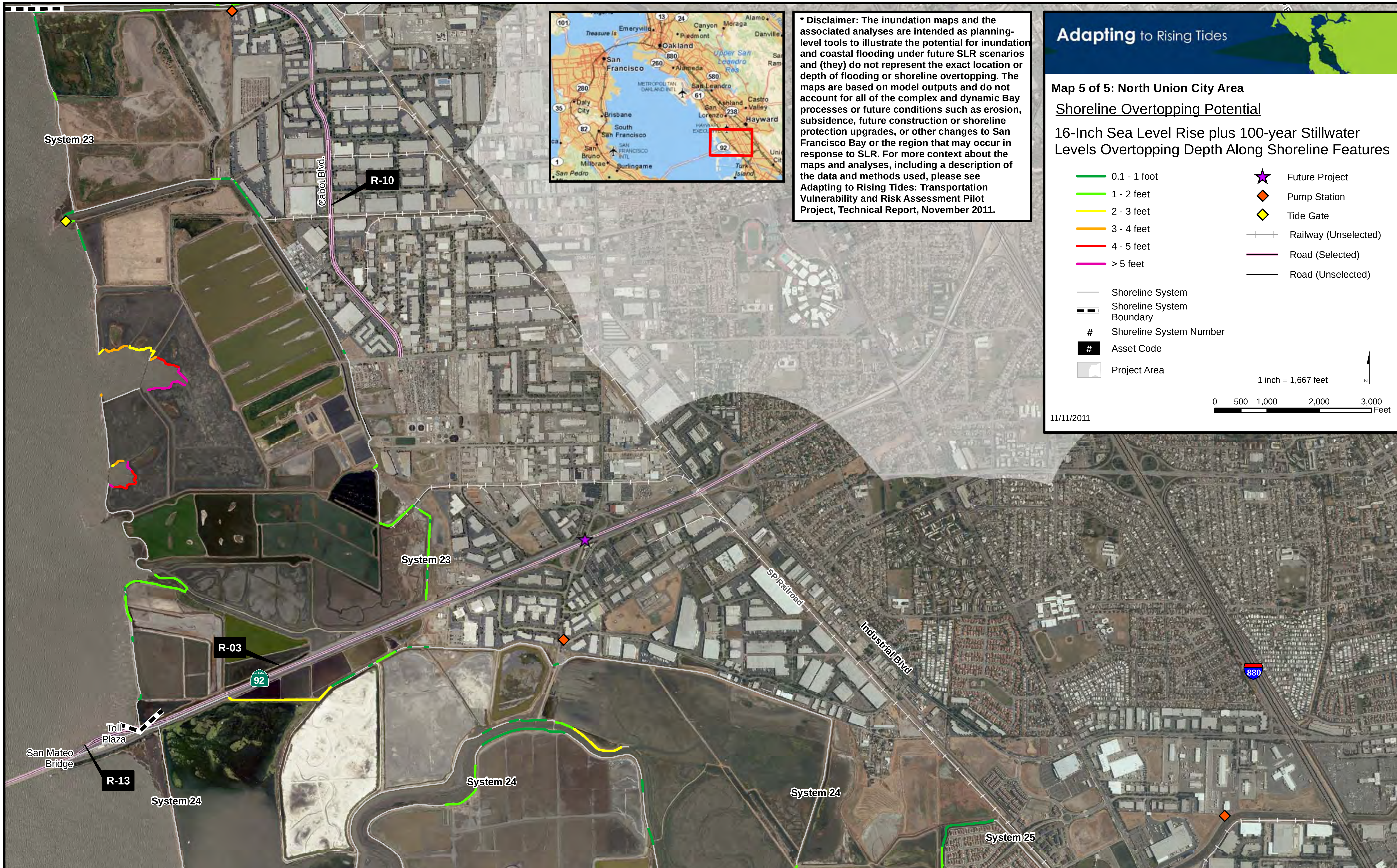
Adapting to Rising Tides
Map 5 of 5: North Union City Area
Shoreline Overtopping Potential
16-Inch Sea Level Rise plus 100-year Stillwater Levels Overtopping Depth Along Shoreline Features
0.1 - 1 foot
1 - 2 feet
2 - 3 feet
3 - 4 feet
4 - 5 feet
> 5 feet
Future Project
Pump Station
Tide Gate
Railway (Unselected)
Road (Selected)
Road (Unselected)
Shoreline System
Shoreline System Boundary
Shoreline System Number
Asset Code
Project Area
1 inch = 1,667 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
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San Francisco
Oakland
Alameda
San Leandro
Hayward
Daly City
Brisbane
South San Francisco
San Bruno
Millbrae
Burlingame
Emeryville
Piedmont
Treasure Is
Castro Valley
System 23
System 24
System 25
R-10
R-03
R-13
Cabot Blvd.
SP Railroad
Industrial Blvd
Toll Plaza
San Mateo Bridge
92
880

Adapting to Rising Tides
Map 1 of 5: Emeryville Crescent - I-80/880/580 Maze Area
Shoreline Overtopping Potential
55-Inch Sea Level Rise plus 100-year Stillwater Levels Overtopping Depth Along Shoreline Feature
0.1 - 1 foot
1 - 2 feet
2 - 3 feet
3 - 4 feet
4 - 5 feet
> 5 feet
Shoreline System
Shoreline System Boundary
Shoreline System Number
Asset Code
Project Area
Unselected Rail Station
Pump Station
BART (Selected)
Railway (Selected)
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 1,650 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
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Northern Project Extent
System 1
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System 3
R-06
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R-12
R-09
R-07
R-04
T-06
T-01
T-02
T-03
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F-04
Powell St
Toll Plaza
Burma Rd
Bay Bridge
Mandela Parkway
West Grand Avenue
UP Martinez Subdivision
BART Transbay Tube
BART
BNSF International Gateway Railport Intermodal Yard
7th Street Highway and Railroad Pumps
San Francisco Bay
Lake Merritt
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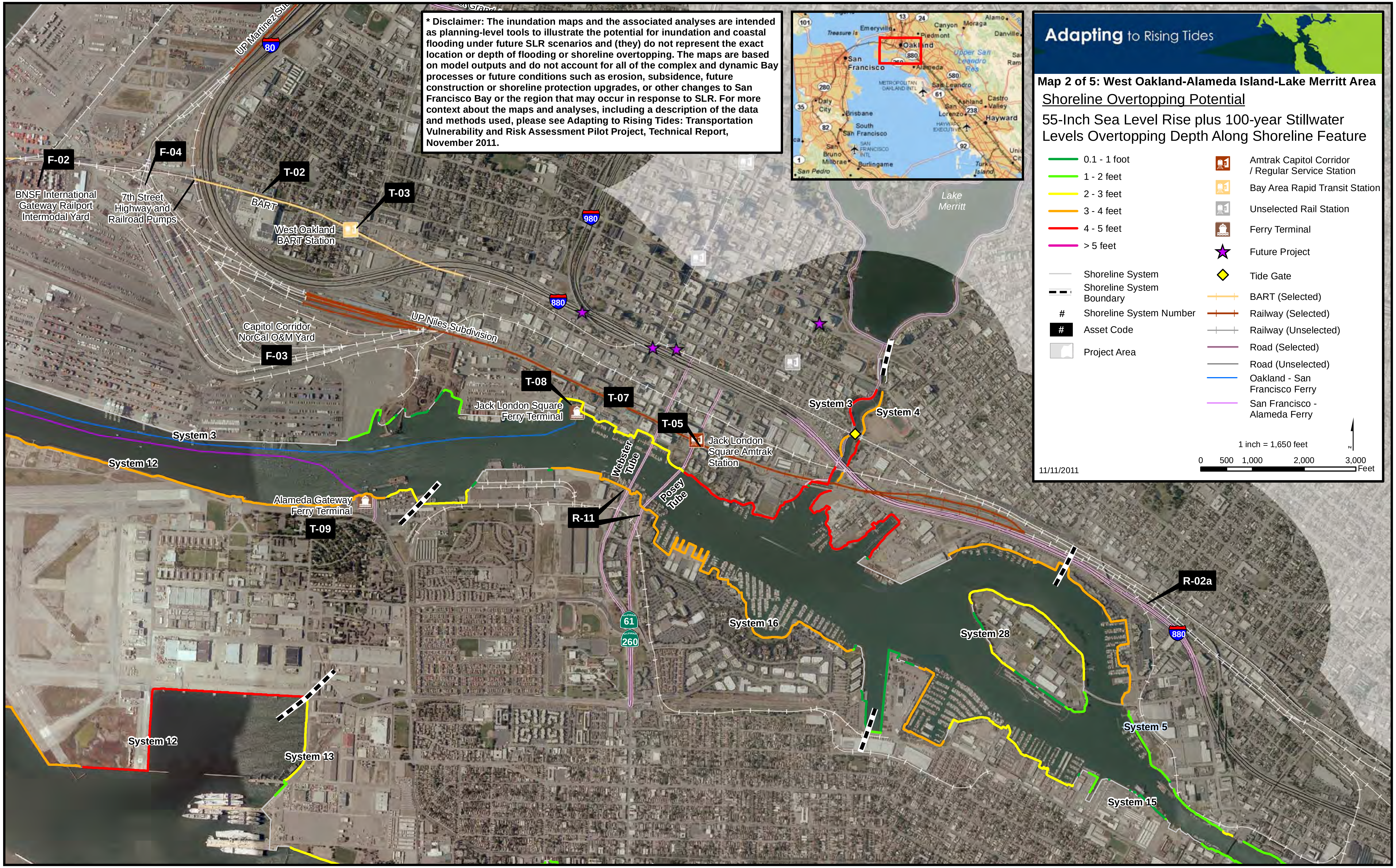

Adapting to Rising Tides
Map 2 of 5: West Oakland-Alameda Island-Lake Merritt Area
Shoreline Overtopping Potential
55-Inch Sea Level Rise plus 100-year Stillwater Levels Overtopping Depth Along Shoreline Feature
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0.1 - 1 foot
1 - 2 feet
2 - 3 feet
3 - 4 feet
4 - 5 feet
> 5 feet
Shoreline System
Shoreline System Boundary
Shoreline System Number
Asset Code
Project Area
Amtrak Capitol Corridor / Regular Service Station
Bay Area Rapid Transit Station
Unselected Rail Station
Ferry Terminal
Future Project
Tide Gate
BART (Selected)
Railway (Selected)
Railway (Unselected)
Road (Selected)
Road (Unselected)
Oakland - San Francisco Ferry
San Francisco - Alameda Ferry
1 inch = 1,650 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
F-02
BNSF International Gateway Railport Intermodal Yard
F-04
7th Street Highway and Railroad Pumps
T-02
BART
T-03
West Oakland BART Station
UP Martinez Sub
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Lake Merritt
UP Niles Subdivision
Capitol Corridor NorCal O&M Yard
F-03
T-08
Jack London Square Ferry Terminal
T-07
T-05
Jack London Square Amtrak Station
System 3
System 4
System 12
Alameda Gateway Ferry Terminal
T-09
Webster Tube
Posey Tube
R-11
R-02a
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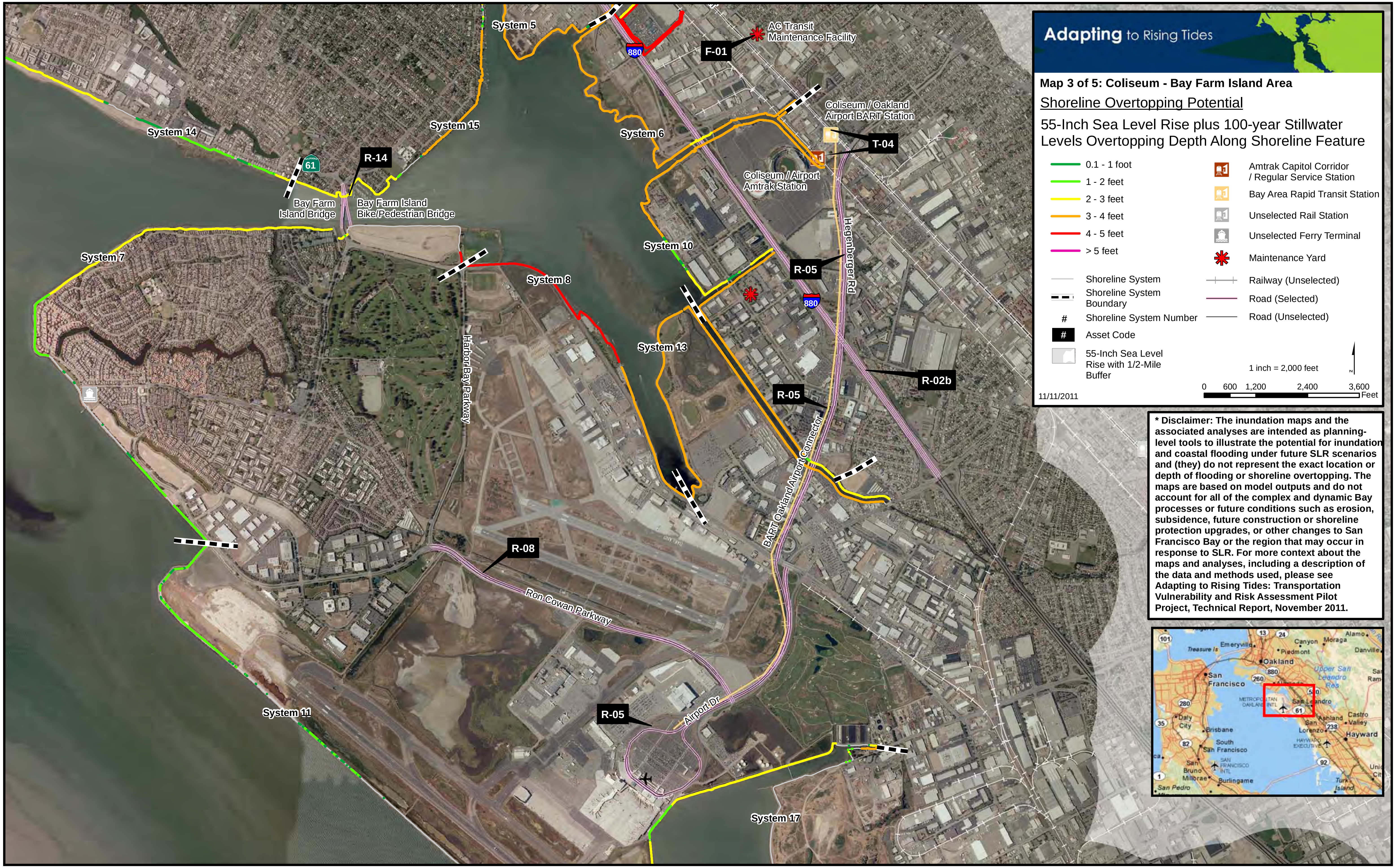
System 5
System 13
System 15


Adapting to Rising Tides
Map 3 of 5: Coliseum - Bay Farm Island Area
Shoreline Overtopping Potential
55-Inch Sea Level Rise plus 100-year Stillwater Levels Overtopping Depth Along Shoreline Feature
0.1 - 1 foot
1 - 2 feet
2 - 3 feet
3 - 4 feet
4 - 5 feet
> 5 feet
Shoreline System
Shoreline System Boundary
Shoreline System Number
Asset Code
55-Inch Sea Level Rise with 1/2-Mile Buffer
Amtrak Capitol Corridor / Regular Service Station
Bay Area Rapid Transit Station
Unselected Rail Station
Unselected Ferry Terminal
Maintenance Yard
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 2,000 feet
0 600 1,200 2,400 3,600 Feet
11/11/2011
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System 5
System 6
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System 10
System 11
System 13
System 14
System 15
System 17
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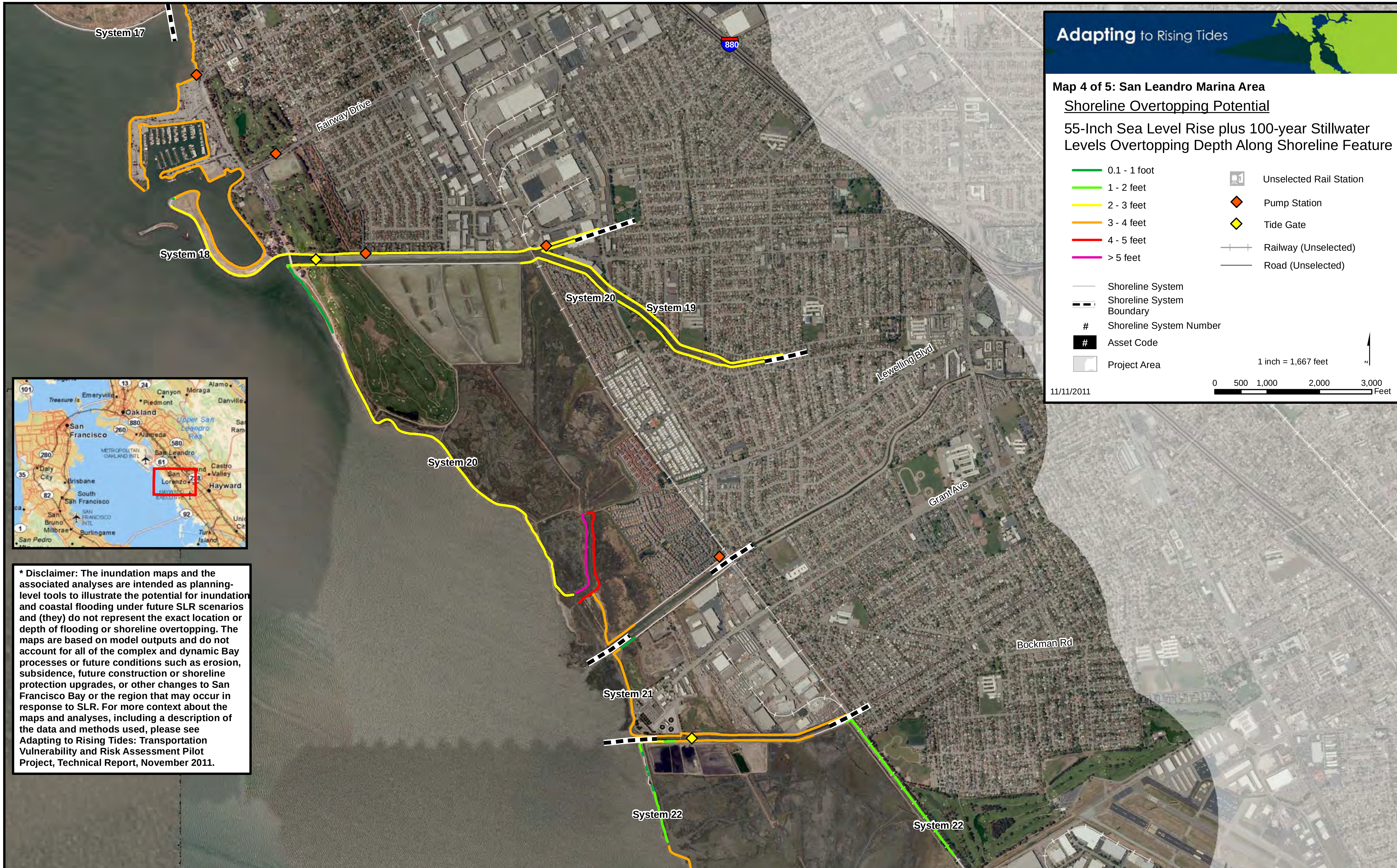
F-01
880
Coliseum / Oakland Airport BART Station
T-04
Coliseum / Airport Amtrak Station
R-14
61
Bay Farm Island Bridge
Bay Farm Island Bike/Pedestrian Bridge
R-05
R-02b
R-08
Hegenberger Rd
Harbor Bay Parkway
BART Oakland Airport Connector
Ron Cowan Parkway
Airport Dr



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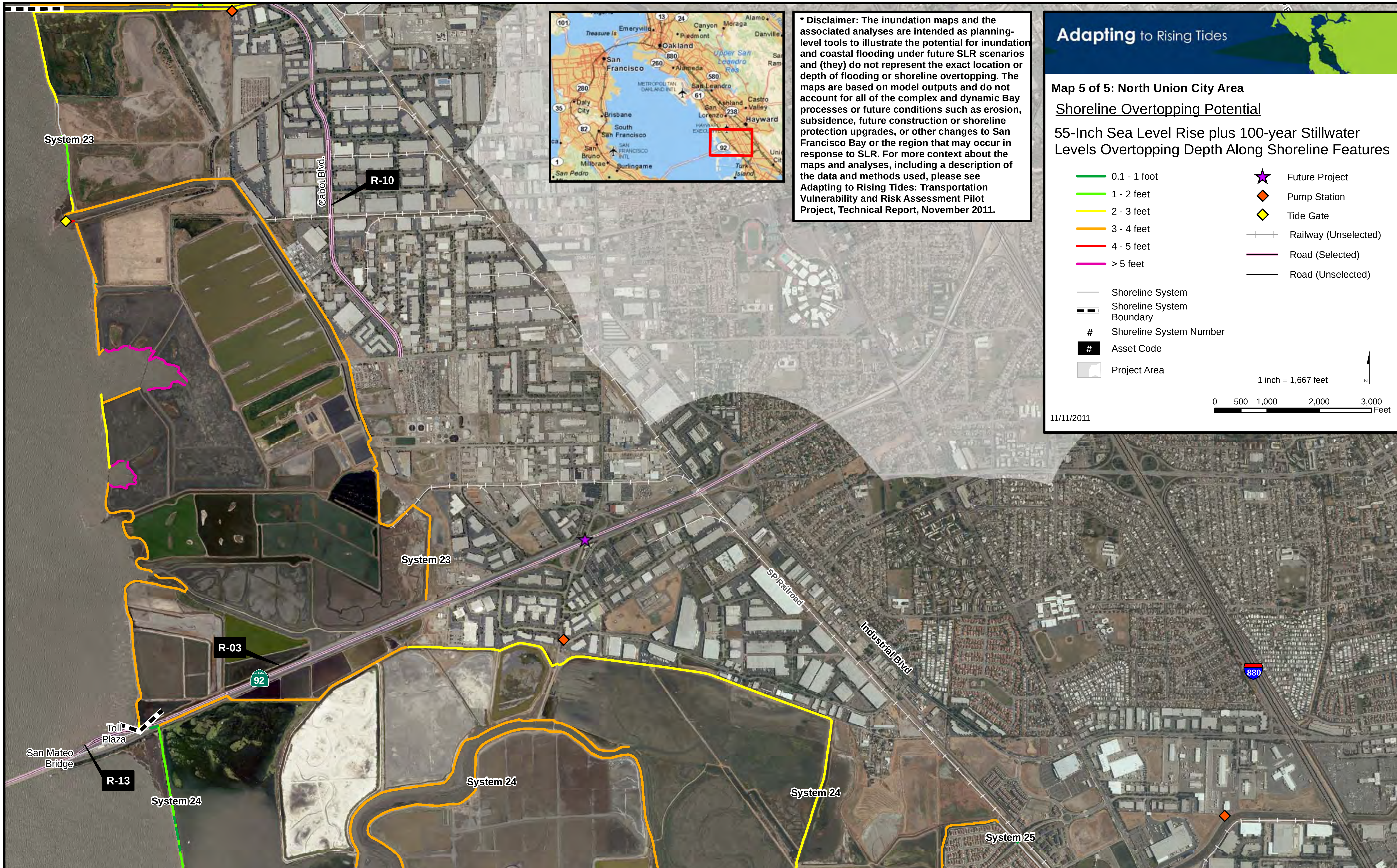
Adapting to Rising Tides
Map 5 of 5: North Union City Area
Shoreline Overtopping Potential
55-Inch Sea Level Rise plus 100-year Stillwater Levels Overtopping Depth Along Shoreline Features
0.1 - 1 foot
1 - 2 feet
2 - 3 feet
3 - 4 feet
4 - 5 feet
> 5 feet
Shoreline System
Shoreline System Boundary
Shoreline System Number
Asset Code
Project Area
Future Project
Pump Station
Tide Gate
Railway (Unselected)
Road (Selected)
Road (Unselected)
1 inch = 1,667 feet
0 500 1,000 2,000 3,000 Feet
11/11/2011
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System 23
R-10
Cabot Blvd.
System 23
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92
Toll Plaza
San Mateo Bridge
R-13
System 24
System 24
System 24
System 25
SP Railroad
Industrial Blvd
880
San Francisco
Oakland
Hayward
San Leandro
South San Francisco
Daly City
Brisbane
Burlingame
Millbrae
San Bruno
Alameda
Emeryville
Piedmont
Treasure Is
Castro Valley
Lorenzo
Ashland
Moraga
Canyon
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Upper San Leandro Res
San Pedro
Turk Island

Adaptation Planning

7.0

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7 Adaptation Planning

7.1 Introduction

Chapter 6 identifies the vulnerability and risk level of the selected representative transportation assets that are exposed to inundation under different sea level rise (SLR) scenarios. The subsequent task is to consider what can be done to mitigate these risks. This chapter explores preliminary ideas and possibilities for adapting to SLR in the pilot project area. Adaptation planning is not part of the Federal Highway Administration conceptual model; however, it is the essential next step in the process.

Section 7.2 reviews a list of potential adaptation measures, some of which were identified through previous planning efforts, including preparation of *San Francisco Bay: Preparing for the Next Level* (BCDC 2009). Section 7.3 provides suggestions on how to use information collected on the risk profiles and additional evaluation criteria to help select adaptation measures. Based on this information, Section 7.4 presents a potential range of near-term and longer term adaptation options for two example assets – the San Francisco–Oakland Bay Bridge (which in this review focuses on the bridge touchdown and toll plaza, R-12) and the Oakland Jack London Square Amtrak Station (T-05). This chapter concludes by recommending next steps for developing an approach to adapting transportation infrastructure to SLR. Consultation with the organizations involved in the Shoreline Asset and Transportation Asset subcommittees would be an essential part of the process.

Note that the adaptation measures presented in this chapter provide a range of possible solutions based only on the information available to the project team. The outcomes of this chapter are not intended to represent specific adaptation measures for the two example assets but rather to identify a range of potential adaptation measures to be further investigated as part of the adaptation planning phase of the ART project.

7.2 Climate Change Adaptation Measures

The risk assessment exercise described in Chapter 6 shows that adapting transportation infrastructure to rising sea levels will be required to maintain the level of service expected within the Alameda County subregion. San Francisco Bay sea levels have already risen by 7 inches (California Natural Resources Agency 2009) in the past century and will continue to rise, and rising tides are already affecting the Bay Area's transportation network. Not adapting to these changing circumstances will likely result in large economic and social impacts to the region. By taking a proactive approach, various agencies around the bay will allow the region to remain safe and competitive.

Key questions to answer at the outset of adaptation planning are: "What is an acceptable impact to the region, and what adaptation measures are needed to achieve this?" In relation to transportation, these questions lead to establishing the minimum level of service that must be provided by the road and rail networks. Under present-day conditions, agencies are likely to require at least the same or a better level of service and the current (or better) level of flood protection. These questions were not addressed for the two example assets reviewed for this project, but it would be a key question in the development of an adaptation strategy.

For this project, adaptation measures have been organized into several categories to structure the discussion on how to select the most appropriate adaptation measures for any given asset – structural and nonstructural measures, and asset-specific and regional (or non asset specific) measures. These categories can be defined as follows:

- Structural Adaptation Measures - are physical measures, such as constructing levees, flood walls, and wetlands or relocating an asset, that mitigate the flooding impacts of SLR.

- Nonstructural Adaptation Measures - are non physical measures that can include changing policies and regulations (e.g., new building codes, zoning requirements like setbacks or buffer zones), updating design guidance, or providing education and community outreach to increase awareness and make communities more resilient. Nonstructural measures could also include rerouting traffic or temporarily closing infrastructure.

- Asset-Specific Adaptation Measures - are measures that are directly related to adapting the transportation asset to SLR impacts.

- Regional Adaptation Measures –are measures that may protect more than one transportation asset and assets in other sectors (e.g., residential, commerce, recreation) in the same area.

Both structural and nonstructural measures are essential for adaptation planning and in many instances, the two complement one another, as the nonstructural measure enables implementation of the structural measure.

In addition, the timing of implementation of adaptation measures can be used as an organizing principle to identify the most appropriate point of intervention in an asset's life cycle for implementation of adaptation measures. Opportunistic adaptation measures are those that can be made during regularly scheduled maintenance or end-of-life-cycle replacement. Proactive adaptation measures are those that are implemented in anticipation of a climate change stressor—in this case, SLR—independent of other activities (e.g., elevating a road before the end of its life cycle to better protect it from rising tides). Consideration of the various categories of adaptation measures and their points of interventions shaped the discussion on conducting an initial screening of appropriate adaptation measures. It should be noted that adaptation measures typically fall into multiple categories, meaning that an asset-specific measure can be, for example, structural in nature as well as opportunistic.

provides an overview of adaptation measures that were found to be potentially applicable for the Alameda County subregion. These measures represent a matrix of structural and nonstructural, and asset-specific and regional adaptation measures. Most of the measures could be implemented as either opportunistic or proactive measures. Note that this table should not be considered an exhaustive list of the potential adaptation options.

Table 7.1 Potential Adaptation Measures Applicable to Alameda County

	Asset-specific	Regional
Nonstructural	- Requiring temporary closure (road, tunnel, bridge) - Rerouting traffic and transit – provide alternative route to reach same destination - Providing alternative mode of transportation (e.g. ferry instead of bridge) - Abandoning the asset and not replacing it - Developing new building and design codes for transportation assets - Revising transportation planning guidance and policy	- Increasing stakeholder and community awareness and input - Increasing technical knowledge and capacity in relevant agencies - Revising land use planning guidance and policy making, including zoning overlays - Developing new and innovative partnerships – to research, fund, and implement climate change adaptation planning.

	Asset-specific	Regional
Structural	- Providing flood/water proofing to better withstand flooding (tunnel entrances, raising electronics within building) - Improving drainage/foundations to retain or drain floodwater - Designing floating structure (roads, ferry terminals) to accommodate future changes in sea level - Using new materials with increased durability to sustain periods of inundation - Raising the asset (road, railroad tracks, tunnel entrance, bridge on ramp, facility, freeway) - Moving the asset – relocate or rebuild an asset to a location at higher elevation outside the floodplain	**Barriers** - Erecting a closure dam (permanent; shorten the line of defense) (e.g., connect Alameda Island to mainland) - Installing a storm surge/tidal barrier (moveable) to close off parts of the bay during high-water events **Levees** - Raising existing levees - Strengthening existing levees (e.g., overtopping resistant) - Incorporating new technology into levees (smart/Intelligent levees), which include flood early warning systems and sensors in levees - Building a new levee (e.g., ring levees) - Building a "super levee" - one so wide it cannot be breached (e.g., ½ mile wide) - Designing a levee in a dune (levee is essentially hidden by a dune, which can become an amenity) - Designing a levee in a boulevard (levee is hidden by a part of the public realm, such as a boulevard) **Walls** - Raising the height of a permanent sea/flood wall - Building a new permanent sea/flood wall - Installing a demountable floodwall - Incorporating buildings (e.g., houses, office buildings, or parking structures) as flood protection features (urban waterfront) **Land Reclamation** - Developing a port or land extension, which will then provide flood protection for the region - Developing new or existing wetlands to dissipate wave energy at the shoreline - Providing foreshore beach nourishment to dissipate wave energy before or at the shoreline - Building with nature (use of the natural forces of streams and currents to strengthen the shoreline) (e.g., use of sediment for wetland or beach accretion for flood protection)

Source: Preparing for the Next Level, 2009; California Climate Adaptation Strategy, 2009; and Adaptation Toolkit: Sea Level Rise and Coastal Land Use, 2011.

Figure 7.1 through Figure 7.8 illustrate several of the adaption measures listed in Table 7.1.

Figure 7.1 Levee Construction

Figure 7.2 Freeway On Top Of A Levee

Figure 7.3 Rendering Of Levee Placed Out Into The Bay And Wetland Development Inboard of The Levee

Figure 7.4 Demountable Floodwall Along Urban Waterfront

Figure 7.5 Glass Wave Overtopping Wall On A Levee

Figure 7.6 Raising Of Existing Levee

Figure 7.7 Residential Development As Flood Protection Barrier

Figure 7.8 Artist Impression Of Levee Combined With Urban Functions

7.3 Methodology to Analyze and Use Risk Profiles for Adaptation Planning

7.3.1 EVALUATION OF RISK PROFILES

The information presented in the risk profiles (Appendix C) provides valuable information to help understand the most appropriate adaptation measure for a particular transportation asset. Transportation assets with the highest risk ratings should be addressed first, as the impacts of SLR are likely to occur sooner, and the consequences are high relative to other assets. The information in the risk profile can be assessed in six steps:

1. *Exposure* – How would the transportation asset be affected by inundation at midcentury, and what would the impacts be at the end of the century (for this example, we have used the 16-inch and 55-inch 100-year stillwater elevation [SWEL] scenarios)? For example:
    a. If the inundation would be less than 1 foot and would occur only during an extreme weather event, then improved drainage, reinforced foundations, temporary closure, or a demountable flood wall may be appropriate.
    b. If the inundation would be permanent and more than 1 foot, then raising the asset, building a flood protection structure, or abandonment of the asset may be appropriate.
2. *Sensitivity* – What characteristics of the asset can be used to understand its sensitivity to climate change stressors? For example:

   a. If the asset is in poor condition, not yet seismically upgraded, or near the end of its service life, opportunistic measures should be taken to raise or reroute the asset, upgrade it with new materials, or waterproof it.
   b. If the sensitivity of an asset can be reduced, the likelihood of occurrence of a climate change impact to this asset can also be reduced. Often, reducing sensitivity in this sense can offer a low cost and fast (interim) adaptation solution.

3. *Adaptive capacity* – How does adaptive capacity affect the vulnerability of the asset, and can this be used as part of an adaptation strategy? For example:
   a. If use of the asset can be wholly or partially rerouted, then structural measures could potentially be avoided; temporary closure could be acceptable in the short term.
4. *Consequence rating* – What are the consequences if this asset is temporarily or permanently out of use? What is its importance to the subregion or Bay Area or beyond? Assets with high consequence ratings should be prioritized for adaptation planning.
   a. If the asset has a high consequence rating, then temporary or partial closure is unlikely to be acceptable; an asset with a low consequence rating, however, could likely be temporarily or partially closed.
5. *Overtopping potential* – Which stretches of shoreline would be overtopped and therefore, would be responsible for inundation of the asset? (An explanation of overtopping is presented in Chapter 4.) For example:
   a. If a short length of shoreline is overtopped, this segment alone could be raised.
   b. If a long length of shoreline is overtopped, a major rebuild, raise, or strengthening of the entire shoreline may be required.
6. *Shoreline systems* – Are there other assets protected by the same shoreline system, and what type of shoreline category does the system consist of? (Descriptions and location of the different shoreline assets are presented in Chapter 2.) For example:
   a. If more than one system or asset is involved, more jurisdictions may need to be involved, and more complex solutions and planning may be required.

Table D1 in Appendix D provides additional examples of how to interpret the information in the risk profiles to inform decisions about potential adaptation measures.

7.3.2 USE OF EVALUATION CRITERIA

After going through these six steps, decision makers can evaluate the adaptation measures (presented in Table 7.1) that may be suitable to reduce the risk of inundation from SLR and the level of service that the adaptation measures will facilitate.

In addition to the categories of adaptation measures, **Error! Reference source not found.**a range of criteria and considerations should be used to evaluate the different adaptation measures, presented in **Error! Reference source not found.**. These criteria have been grouped according to the lenses of economy, ecology, equity, and governance, defined in the larger Adapting to Rising Tides project:

- Equity – Addresses the effects on communities and the services on which they rely, with specific attention to disproportionate impacts due to existing inequalities.
- Economy – Addresses the economic values that may be affected, such as costs of physical/infrastructure damages or lost revenues during periods of recovery.
- Ecology – Describes the environmental values that may be affected, including ecosystem function and services and species biodiversity.
- Governance – Addresses factors such as ownership, management responsibilities, jurisdiction, mandates, and organizational structure that influence vulnerability and resilience.

Table 7.2 Criteria for Helping Selection of Adaptation Measures

Economy	Ecology
- *Protection of functionality* – Although the continued use of the asset may be limited, the function of the system as a whole can be protected if other facilities (e.g., Bay Area Rapid Transit [BART] or ferries, alternative routes) can provide the same or similar functionality. - *Protection of asset* – When the asset is protected, the asset could still be used. - *Economic benefit* – Does the improved flood protection/climate resiliency spur new investment or growth? - *Cost and time to build* – What are the time and costs associated with implementing the adaptation measures? - *Operation and maintenance cost* – What are the operation and maintenance costs? - *Spatial requirements* – How much land is required to implement the adaptation measure? - *Adaptability* – Can an adaptation measure be designed to adapt to future climatic changes as likelihood increases or new technologies become available? - *Applicability in time* – Which measures are appropriate for the midterm and which for the longer term, given different SLR scenarios?	- *Ecological value* – Does the adaptation measure provide benefits to the natural environment through species or habitat protection? - *Ecological function* – Does the adaptation measure improve ecological function (e.g., wetland vs. flood wall)? - *Sustainability (longevity)* – Do the different adaptation measures provide long-term sustainable solutions (e.g., next 50, 100, or 200 years)? - *Sustainability (materials)* – Are the materials used for the adaptation measure environmentally sustainable? - *Environmental impacts* – What are the environmental impacts of implementing the adaptation measure, can they be mitigated, and do they reduce green house gas emissions?
Equity	**Governance**
- *Safety*- does the adaptation measure enhance public safety and security? - *Environmental justice* – does the adaptation measure benefit underserved populations? - *Regional benefit* – Is there a regional benefit to the local community selecting a specific adaptation measure (e.g., systems approach to protect the region vs. asset-specific protection)? - *Awareness* – Does the measure enhance public awareness and technical knowledge about SLR? - *Public access and aesthetic importance* – Can the adaptation measure be integrated into the natural or urban landscape so that it becomes an amenity and (for example) provides public access to the shoreline? - *Unintentional consequences* – Are there beneficial or negative consequences to the surrounding community or other assets by implementing this measure?	- *Institutional (organizational) arrangements*, *including jurisdiction* – Are governmental bodies and current policies and regulations equipped to ensure or facilitate long-term planning and timely implementation of the adaptation measure? - *Funding* – Which organization is providing the funding for the adaptation measure, and are there funds available? - *Public or private land* – Which entity or individual owns the land, and how does this affect implementation of the adaptation measure? - *Policies* – Does the adaptation measure build on existing policies, and do new policies allow for modifications as new climate change data/insights become available? - *Development* – does the adaptation measure facilitate (undesired) development in low lying areas (through improving the flood protection level)?

Different weightings or rankings of importance can be applied to the criteria presented in Table 7.2. For example, more emphasis could be placed on the level of service an asset provides and its implementation cost (in the face of SLR). Whether to assign weightings to the criteria (or rankings of importance) is a determination to be made by transportation agencies. (Note that weightings were not assigned to the criteria for the example assets discussed in this chapter, but should be considered a potential approach by agencies when reviewing adaptation options for specific assets in the subregion.)

(Also note that the likelihood of climate change impacts occurring needs to be reviewed regularly, along with updates to regional climate modeling data, in case predictions regarding the depth and timing of SLR change (from the 16 inches predicted for midcentury and the 55 inches predicted for the end of century).

7.4 Example Assets

The two example assets selected to test the methodology presented in this chapter are the San Francisco-Oakland Bay Bridge, focusing on the bridge touchdown and toll plaza (R-12), and the Oakland Jack London Square Amtrak Station (T-05). These two assets were selected because they represent two different categories of transportation assets and are close to the shoreline. Assets close to the shoreline were selected to avoid overlapping with other sectors (e.g., communities, land) being addressed in the larger Adapting to Rising Tides project.

A range of adaptation measures can be considered from the options presented in Section 7.2 and the information provided by the risk profiles, as discussed in Section 7.3. The Project Management Team and the Consultant Team held a joint work session to select potentially applicable measures looking at midterm (16 inches + 100-year SWEL) and end-of-century (55 inches + 100-year SWEL) SLR scenarios for the two example assets. This was an initial, qualitative assessment that will need further investigation to determine the real cost-effectiveness, applicability, and viability of proposed adaptation measures. The structural measures discussed in this session are further described in Sections 7.4.1. and 7.4.2. Due to time constraints, nonstructural adaptation measures were not discussed during the meeting, but a narrative with some suggested measures is provided in Section 7.4.3. Note that the adaptation measures described cannot be seen in isolation of one another— ultimately, a system consisting of a combination of different types of adaptation measures, both structural and nonstructural, will have to be developed to protect against inundation from SLR.

7.4.1 SAN FRANCISCO–OAKLAND BAY BRIDGE

The San Francisco–Oakland Bay Bridge connects Alameda County with the City and County of San Francisco. For this assessment, the bridge touchdown on the Oakland side and toll plaza are considered. Also note that the Bay Bridge does not function in isolation and should be considered in relation to the freeways it connects with.

A review of the risk profile identifies that:

1. The *exposure* is rated medium because the bridge would be inundated only under the 16 inches + 100-year SWEL and 55 inches + 100-year SWEL SLR scenarios. However, under both scenarios, significant inundation could occur (2 and 5 feet) that could be exacerbated by wind wave effects.
2. The *sensitivity* of the asset is high because of the high level of use and very high liquefaction potential (although the new span under construction is being built to current seismic standards). Given its high operations and maintenance (O&M) costs, opportunistic measures could be considered as part of scheduled maintenance and upgrades to the facility.
3. Some *adaptive capacity* is provided by the alternative routes of BART and ferries, but this is likely inadequate for the volume of commuters and for goods movement. Given its limited adaptive capacity, structural adaptation of either the asset or the region will be critical.
4. The *consequence rating* for this asset is high due to its high level of use and importance to the region, limiting options for temporary or partial closure during inundation under the midcentury scenario.
5. The bridge touchdown and toll plaza are protected by Shoreline System 2, which is a combination of engineered shoreline protection and natural shoreline (wetlands). The overtopping potential at midcentury and at the end of the century is quite high: 10,510 feet of shoreline would be overtopped by midcentury at an average depth of 1.7 feet, and at the end of the century, more than 16,900 feet would be overtopped at an average depth of 3.9 feet for the 16 inches + 100-year SWEL and 55 inches + 100-year SWEL SLR scenarios, respectively. Asset-specific adaptation could, therefore, still have significant impacts on the region surrounding the asset. Other transportation assets that are affected by overtopping of Shoreline System 2 include other parts of Interstate 80 (I-80), West Grand Avenue, Mandela Parkway, Burma Road, 7th Street Highway and Railroad Pumps (55 inches), and Union Pacific Martinez subdivision.

Table 7.3 provides an overview of potential adaptation measures for the San Francisco-Oakland Bay Bridge. These measures are described in more detail in the paragraphs below.

Table 7.3 Suggested Potential Adaptation Strategies for the San Francisco-Oakland Bay Bridge

	Midcentury	End-of-Century
Asset-specific adaptation	- Improve drainage - Retrofit – make waterproof - Raise touchdown and toll plaza area - Partial closure	- Raise road surface - Build causeway
Regional adaptation (along Shoreline System 2)	- Create berm - Wetland restoration/ creation - Construct floodwall	- Build levee - Build floodwall - Wetland restoration/ creation
Nonstructural adaptation	- Develop new building and design codes - Revise transportation planning guidance and policy - Form multi-jurisdictional partnerships	- Continue implementation and revision of nonstructural adaptation measures as needed

ASSET-SPECIFIC ADAPTATION

Near-term and midterm asset-specific adaptation for the Bay Bridge touchdown and toll plaza seems to be a viable option, as limited inundation will occur under the midcentury scenario. Minor modifications to the asset can be made in an opportunistic manner during scheduled maintenance to mitigate for future inundation to improve resilience to flooding. The following adaptation measures are considered for this location:

- Improve drainage – The drainage system around the freeway and the toll plaza could be improved so that when inundation occurs, there might be only partial closure of the roadway and, after a storm/high tide event, water would drain off the road surface quickly enough to minimize disruption. This measure can be considered “low regret” adaptation.
- Retrofit – To minimize the consequences of temporary inundation for the physical infrastructure of the asset, retrofitting can be considered. For the toll plaza, this would require that water-sensitive elements (such as wiring and electronics) be placed above a certain flood elevation. Entrances to buildings, buildings themselves, and toll booths can be made flood resilient through water proofing so that they can withstand temporary inundation. This measure would assume periodic partial or temporary closure of the freeway. (The level of service required would determine whether this adaptation response is considered adequate.)
- Raise road surface – As part of regularly scheduled maintenance for the midcentury planning horizon, raising the road in areas identified as vulnerable to inundation could be considered.
- Conduct partial or temporary closure – A nonstructural/management option during extreme events could be to close part or all parts of the freeway. (The level of service required would determine whether this adaptation response is considered adequate.) It is unlikely that recurring closure would be acceptable.

For the end-of-century scenario, minor modifications to the bridge touchdown and toll plaza would not likely be adequate to address the projected inundation. Given the potential consequences of this impact, the following more drastic adaptation measures can be considered:

- Raise road surface – Rather than raising the road during regularly scheduled maintenance, a more proactive approach could address greater inundation levels. The entire freeway could be elevated above the end-of-century 100-year storm level. Although this is described as an asset-specific measure, it might also provide benefits to the region because the raised road could serve as a levee protecting West Oakland.
- Build causeway – The freeway leading up to the Bay Bridge could be transformed into a causeway bridging the low-lying areas, similar to the Hayward–San Mateo Bridge that spans part of the bay. It would be very expensive, however, to accommodate a toll plaza on a causeway.

REGIONAL ADAPTATION

For the midcentury scenario, with only minor modifications to the landscape, most of the bridge touchdown, the toll plaza, and I-80 leading up to the bridge could be protected from inundation, which would also protect a wider area. Note that these adaptation measures would become part of a flood control system that might extend beyond the immediate area to create a closed flood protection system:

- Create berm – Along the perimeter of the freeway and the off- and on-ramps, a berm could be constructed to keep rising tides back. With this measure, the drainage system of the freeway and toll plaza would need to be altered, and pumps might be needed to pump out stormwater. This berm could be constructed such that it allows for modifications in the future to withstand greater SLR.
- Support wetland growth – Wetlands are able to absorb wave action and can reduce flood elevations at the asset. Wetlands are located along the north side of the toll plaza and I-80. If wetlands are able to grow organically with SLR (through sediment deposition, for example) they provide a natural and attractive form of flood protection. Note that fringing wetlands can reduce the flooding only associated with waves. High tide and storm stillwater levels would still inundate the shoreline unimpeded. A

recent study by PRBO Conservation Science (PLoS 2011), however, indicates that it is unlikely that Bay Area marshes will be able to keep pace with anticipated SLR at the end of the century.

- Construct floodwall – A small floodwall could be constructed along the perimeter of the freeway to prevent flooding and wave overtopping at the asset. A floodwall would impair the existing drainage system, which would therefore have to be modified as well (e.g., installation of pumps).

Regional adaptation at the end of the century would require greater interventions to deal with the potential inundation scenarios. Without major interventions, it is unlikely that wetlands would be able to address a 55-inch SLR scenario and would reduce the impacts of flooding associated only with waves.

- Construct levees – A berm built at midcentury could be reconstructed as a levee. As discussed under asset-specific adaptation, an elevated freeway could also be built on top of a new levee, which would also serve a regional flood protection function.
- Construct floodwall – A flood wall built at midcentury could be strengthened and raised.
- Support wetland growth/build wetlands – As stated earlier wetlands are able to absorb wave action and can reduce flood elevations at the asset. It is unlikely that wetlands will accrete to the end of century level of SLR. Therefore, wetland growth could be supported by beneficial use of dredged material. However, to provide proper flood protection, this measure likely should be integrated with the construction of a levee or floodwall further inland.

NONSTRUCTURAL ADAPTATION

As stated earlier, given the importance of this asset, temporary closure, rerouting traffic, using an alternative mode of transportation or even abandoning the asset are not considered viable options for non-structural adaptation measures. Measures specific to this asset include:

- Changes to building codes and design guidance – As new designs and plans are made for construction, retrofitting, or maintenance, they should include guidance on how to adapt to SLR. This guidance can help enable the implementation of structural measures, such as improving drainage, raising the road surface, or making structures around the touchdown and toll plaza more resilient to flooding.
- Modification of policies and planning guidelines – For proactive planning and to facilitate adaptation to rising sea levels, existing policies for SLR and flood management for this asset should be reviewed and revised.
- Multi-Jurisdictional Partnerships – Since areas inland of the San Francisco-Oakland Bay Bridge peninsula are vulnerable to flooding that originates at the shoreline of this facility, exploring partnerships with the Port of Oakland, City of Oakland and City of Emeryville may facilitate cost-sharing or implementation of structural solutions needed to address vulnerabilities and risks identified in the risk profile. The Bay Bridge Peninsula is currently the subject of a collaborative planning effort being conducted by Caltrans, the Bay Area Toll Authority, the Port of Oakland, City of Oakland, BCDC, the East Bay Regional Park District and East Bay Municipal Utility District to facilitate redevelopment of the peninsula for a mix of uses. This partnership could expand its focus to address adaptation solutions in conjunction with other planning.

7.4.2 OAKLAND JACK LONDON SQUARE AMTRAK STATION

The Oakland Jack London Square Amtrak Station is an at-grade, multi-modal facility on the Capitol Corridor. Although the risk profile assesses only the station and the passengers that pass through the station, the Union Pacific Niles subdivision railroad track serving the station is also an important goods movement corridor for the Port of Oakland, and the tracks would be affected by inundation near the station and at other locations in the subregion. Although the impacts to the station itself can be limited, the major concern is the inundation of railroad tracks both close to the station and at other locations in the subregion.

A review of the risk profile identifies that:

1. The *exposure* is rated medium for this asset because inundation under the 55 inches + 100-year SWEL SLR scenario would be about 1 foot. There would be no impact on the station at 16 inches + 100-year SWEL, except for potential wind wave impacts by midcentury. The railroad tracks would be affected under the 16 inches + 100-year SWEL scenario. Given the minor impacts at midcentury, these could likely be mitigated with little intervention, if any.
2. During the study, limited information was available on *sensitivity* for this asset. More information should be obtained to investigate if implementation of any adaptation measure could go along with scheduled maintenance or construction.
3. The *adaptive capacity* is inadequate, with the nearest station along the line (Emeryville) located 4 miles away. This means that adaptation of the asset or the shoreline protecting it is necessary.
4. *Consequence* is rated moderate for time to rebuild and commuter use and low for all other considerations. The overall consequence rating makes the station a low-risk asset. This could imply that temporary closure might be an option.
5. Shoreline System 3 protects the Amtrak station. Although the shoreline would be overtopped at 16 inches + 100-year SWEL, this overtopping would result in minimal inundation on land in the vicinity of the asset and no inundation at the asset. At 55 inches + 100-year SWEL, the overtopping of the shoreline would be significant, with an average overtopping depth of 2.6 feet and more than 20,000 feet of the shoreline overtopped.

Many other assets are protected by Shoreline System 3, including 7th Street Highway and Railroad Pumps (55 inches), Capitol Corridor Norcal O&M Yard, Burlington Northern Santa Fe International Gateway Intermodal Yard, Jack London Square Ferry Terminal, elevated BART line (Transbay Tube and Oakland Wye). However, not all these assets would be inundated from shoreline overtopping close to this train station.

Table 7.4 provides an overview of potential suggested adaptation measures for the Oakland Jack London Square Amtrak Station. These measures are described in more detail in the paragraphs below.

Table 7.4 Potential Suggested Adaptation Strategies for the Oakland Jack London Square Amtrak Station

	Midcentury	End-of-Century
Adaptation of asset	- Limited impacts – consider revising asset management plans to incorporate considerations of end of the century impacts	- Improve drainage - Retrofit – make waterproof - Temporary closure - Raise station and/or track - Relocation
Regional adaptation (along Shoreline System 3)	- Limited impacts – consider revising shoreline protection plans to incorporate considerations of end of the century impacts	- Construct floodwall - Build levee - Integrate flood protection in urban fabric
Nonstructural adaptation	- Temporary closure - Providing alternative mode of transportation - Abandoning the asset and not replacing it - New building and design codes - Revision of planning guidance and policy	- Continue implementation and revision of nonstructural adaptation measures as needed

ASSET-SPECIFIC ADAPTATION

There would be very little impact on the Oakland Jack London Square Amtrak Station under the midcentury SLR scenario, apart from possible wind wave effects. Therefore, the range of potential adaptation measures focuses on the end-of-century SLR scenario. Minor modifications to the asset can be made in an opportunistic manner during scheduled maintenance to mitigate for future inundation to improve resilience to flooding.

- Improve drainage – The drainage system around the station could be improved so that when inundation occurs, the station itself might not be affected, or at least would be only temporarily closed. Improved drainage would enhance the resiliency of the station and would drain off floodwater more quickly.
- Retrofit – Modifications to entrances of the station would minimize the volume of floodwater that might inundate the station, and placing water-sensitive elements (such as wiring and electronics) above a certain flood elevation would minimize damage in the event of flooding. Temporary closure of the station might still be required under this measure.
- Raise railroad track and/or station – The station and the railroad tracks could be raised above the level of inundation. However, raising the railroad track adequately might be difficult or very expensive because many other transportation assets (e.g., bridges) cross the tracks, and adequate clearances must be maintained.
- Conduct partial or temporary closure – A nonstructural/management option during extreme events could be to close part or all of the station. (The level of service required would determine whether this adaptation response is considered adequate.) It is unlikely that recurring closure would be acceptable. In the case of such closures, passengers using the station could be served at adjacent stations (e.g., Emeryville or Oakland Coliseum), or “bus bridges” could connect passengers traveling to/from the Jack London Square area with trains at other locations. An alternative route for goods traffic is less readily available.

REGIONAL ADAPTATION

Regional adaptation for the Oakland Jack London Square Amtrak Station and tracks would mean protecting the area around Jack London Square and the Lake Merritt Channel:

- Construct permanent or temporary floodwall/barrier – With the heavily developed and engineered waterfront at Jack London Square, there is limited space available to construct flood protection. Temporary or permanent floodwalls or barriers that have a small footprint could be considered. Temporary barriers could be used as an early adaptation measure and installed, with proper forecasting, before a storm event. Permanent floodwalls could be considered as a measure for the longer term and could be integrated into the design of the waterfront.
- Build levee – The waterfront of Jack London Square is not suitable for the construction of a levee. Levees could be considered along the Lake Merritt Channel but could significantly affect the recreational values along the Lake Merritt Connector Trail. With this measure, raising of the railroad tracks at the channel might still be needed.
- Integrate flood protection into the urban fabric – As the waterfront of Jack London Square is renewed and redeveloped over the next decades, building codes could be modified so that new development along the waterfront (e.g., residential or commercial) also serves as flood protection barrier and becomes an integrated part of a flood protection system.

NONSTRUCTURAL ADAPTATION

Due to its low level of use, more nonstructural measures are possible for this asset than for the Bay Bridge (R-12). Measures that can be taken at this asset include:

- Temporary closure – If the area surrounding the station is temporarily inundated and the tracks are still operable, then temporary closure of the station can be an option.
- Providing an alternative mode of transportation – Along with the measure above passengers can be offered a different mode of transportation (to get to the Emeryville station for example). Providing an alternative for goods movement that passes through the station is considered less viable.
- Abandoning the asset – If the inundation impacts are too great and the capital expense to modify the asset is not justified, abandoning the station could be considered.
- Revision of building codes and design guidance – To enable the implementation of structural measures, such as improving drainage, raising the railroad tracks or making the station itself more resilient to flooding or providing design guidance or alternative building codes can be considered to ensure future use of the station.
- Policies and jurisdiction – With the location of the station in a heavily urbanized area and with many government agencies involved that are responsible for transportation, land use planning and flood protection, all with overlapping responsibilities, it will be difficult to make specific policy changes related to flood management/SLR geared to this asset alone . Regional coordination will be needed to accommodate this.

7.4.3 NONSTRUCTURAL REGIONAL ADAPTATION MEASURES

An integrated regional adaptation strategy also should involve nonstructural regional measures. Some of the regional nonstructural measures relevant for both the example assets that could be considered by transportation and planning agencies in developing SLR adaptation plans include:

- Stakeholder and community awareness and input – To gain critical public understanding of, and support for, implementation of climate change adaptation plans, public education and outreach could be conducted. Stakeholder input is also essential to help identify and shape the most appropriate adaptation measures for a given asset and location, particularly if the measure may have regional impacts. Outreach also provides an opportunity to explain how local planning decisions should be informed by detailed risk and vulnerability assessments to ensure the prioritization of actions. These efforts help to create greater awareness and a more resilient community.
- Increased technical knowledge and capacity – To allow agencies to better understand the impacts of climate change and the different options for adaptation, further research and education is needed. Building up the level of knowledge and technical capacity through research and education would allow for development of new climate change adaptation plans and smoother implementation.
- Planning and policy making – This option was also discussed as part of the asset-specific measures. However, many planning and policy-making decisions are made at the regional level and then applied at the local level or in this case, to specific assets. Many existing government policies do not yet take SLR into account and need to do so. This applies to planning policy and guidance documents, building codes, design standards, and zoning requirements, for example. California and the Bay Area, in particular, however, are quite progressive when it comes to addressing climate change issues and are leaders in the United States. This is demonstrated, for example, by the Ocean Protection Council Guidance on SLR, California Department of Transportation guidance on SLR, and the recent Bay Plan Amendment of the San Francisco Bay Conservation and Development Commission. The Bay Plan Amendment requires new development along the bay potentially affected by 16 inches of SLR to conduct a vulnerability assessment and, if vulnerable, clearly describe the economic and/or ecological benefits of the project. For transportation planning, local and regional entities will be looking for guidance from other regional and state organizations on how to incorporate climate change into planning.
- Funding – Funding is needed to conduct further vulnerability assessments and adaptation planning analyses and implement climate change adaptation plans for both example assets. Adapting to rising tides will inevitably bring additional costs to their capital improvement projects. Funding can be sought through traditional mechanisms, but also new funding methods could be considered, such as through public private partnerships and new or other user fees. Planning proactively for SLR now should avoid major unexpected costs in the future. In addition, being prepared for the risk of climate change should attract new investments and make the Bay Area more competitive compared to other regions around the world.
- New and innovative partnerships – To research, fund, and implement climate change adaptation planning, new partnerships should be fostered to explore and establish cooperation among research institutions, governments, nonprofit organizations, and business entities to prepare for climate change. This can involve public private partnerships, in which a new commercial or residential development funds (part of) the climate change adaptation measures protecting a larger area. The business community can potentially take the lead in driving the climate adaptation debate and spur government and related agencies to take proactive measures to keep the region competitive. This could involve new partnerships to share knowledge and expertise on climate adaptation because many other regions will be affected by SLR.

7.5 Next Steps in Adaptation Planning

This chapter provides preliminary suggestions for potential climate change adaptation measures for the Alameda County subregion, but this is only the first step in developing an adaptation plan. The wealth of information that has been generated in this pilot project can be more thoroughly analyzed for all the selected representative assets to inform further decision making on adaptation measures. Stakeholder consultation will be a vital part of this process. The Adapting to Rising Tides program will take the outputs from this study to inform the 2012 and 2013 adaptation planning efforts for all sectors within the subregion. As it specifically relates to transportation planning, the following potential projects are recommended:

- Prepare further vulnerability and risk assessments of some of the transportation assets that could not be included in this study because of time and budget constraints, using the methodology developed as part of the pilot project and drawing on the new inundation mapping. In addition, a more in-depth analysis of the inundation mapping and shoreline overtopping information for specific transportation assets could be carried out to better understand the potential impacts under different storm scenarios and to inform the selection of adaptation measures.
- Conduct a more detailed alternatives analysis and feasibility study of different climate change adaptation measures at selected locations, reviewing all the criteria (relative to economy, ecology, equity, and governance) outlined in Table 7.1 This study could be accompanied by visualizations of adaptation measures under different SLR scenarios. These results can then be discussed with stakeholders to identify the most appropriate and cost-effective solutions.
- Conduct traffic flow and economic impact analyses to understand the primary and secondary effects of reduced mobility in the Bay Area attributable to SLR inundation of transportation assets.
- Ensure that all assets due for upgrade, repair, or retrofit in the near future are reviewed for adaptation opportunities, particularly in terms of new materials, drainage, and waterproofing improvements.
- Develop a SLR or climate change preparedness plan for the Metropolitan Transportation Commission that serves as a guidance document for local and other regional transportation agencies on how they can incorporate SLR into their own transportation planning.

7.6 References

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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).

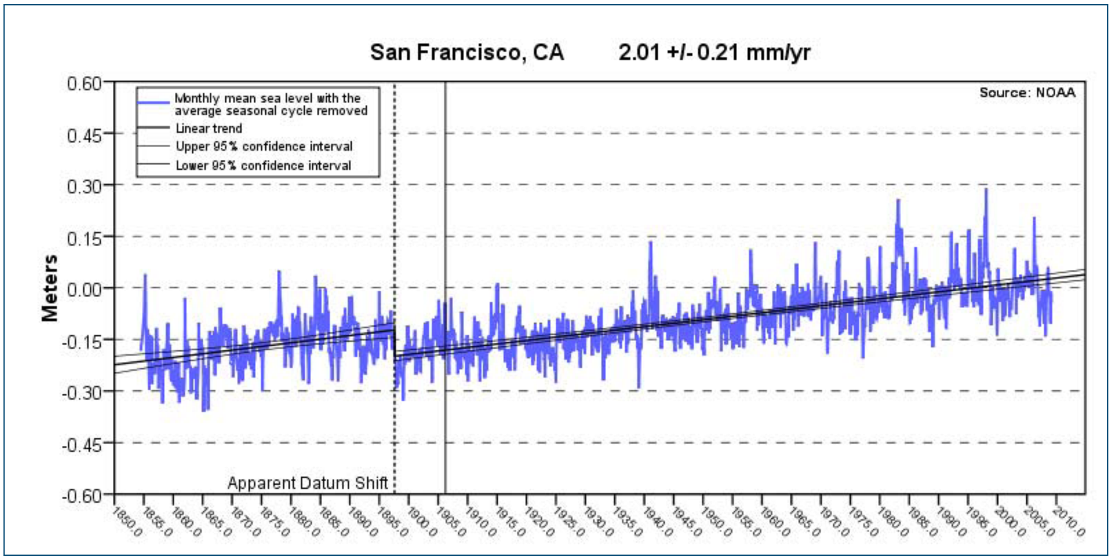

Figure B4.1. Monthly Mean Sea Level at the San Francisco Tide Station: 1854–2006

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.

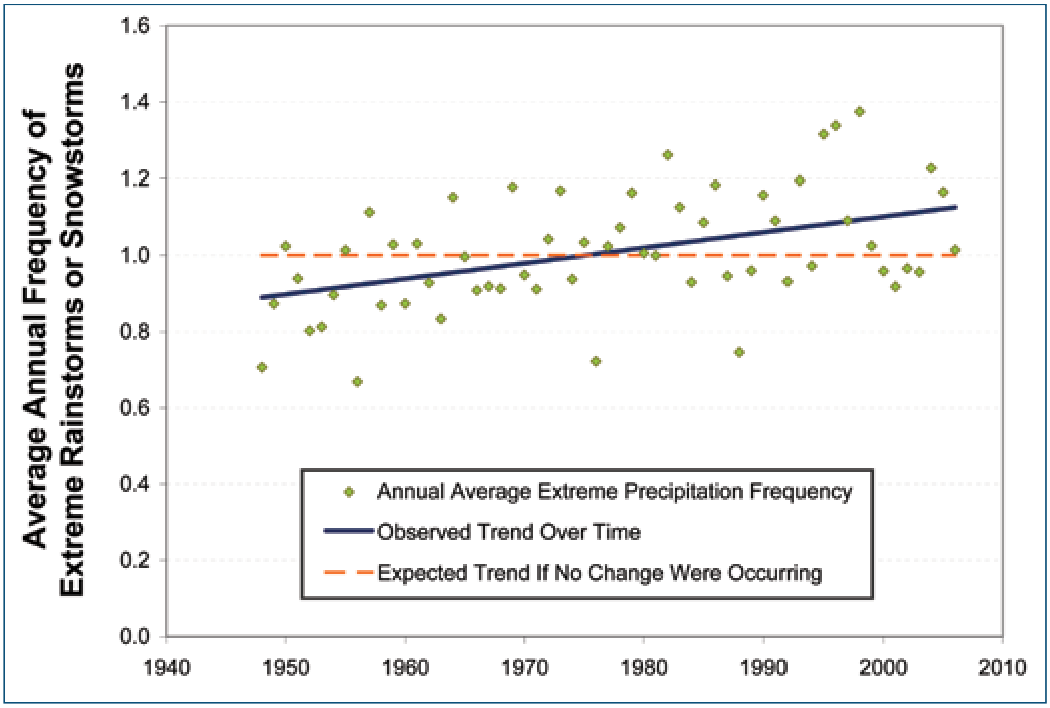

Figure B4.2. Annual Average Frequency of Storms with Extreme Precipitation in the United States, 1948–2006

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.

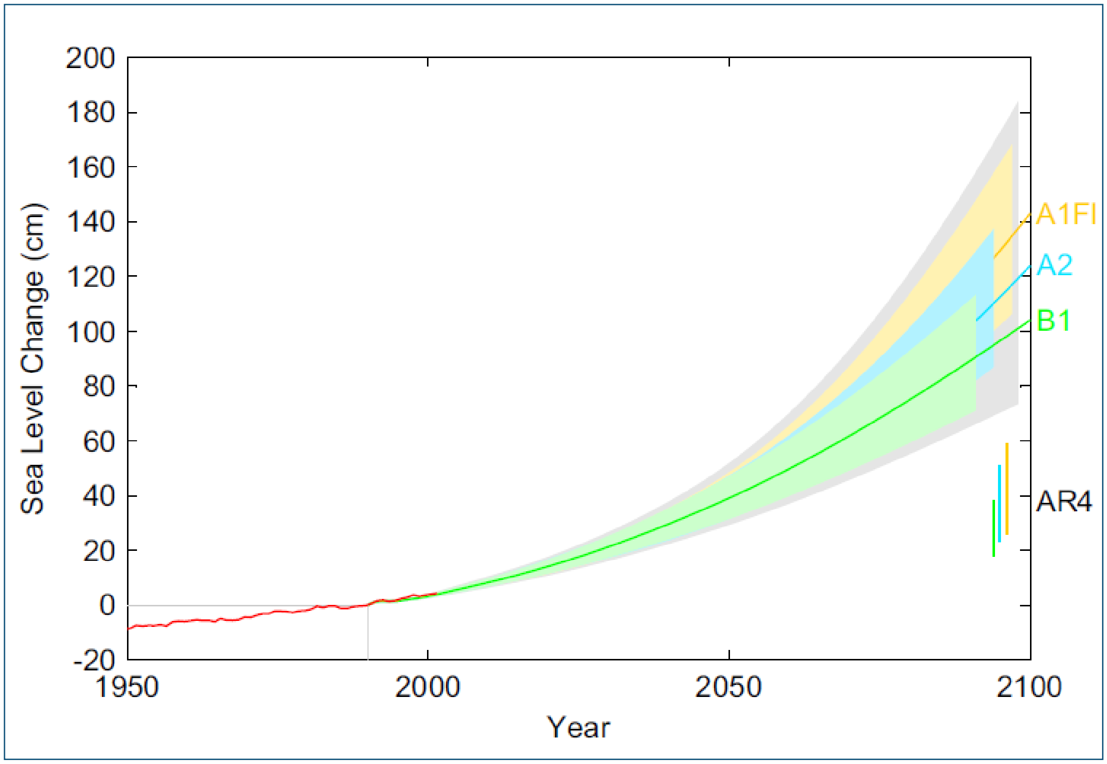

Figure B4.3. Projected SLR: 1990–2100

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.

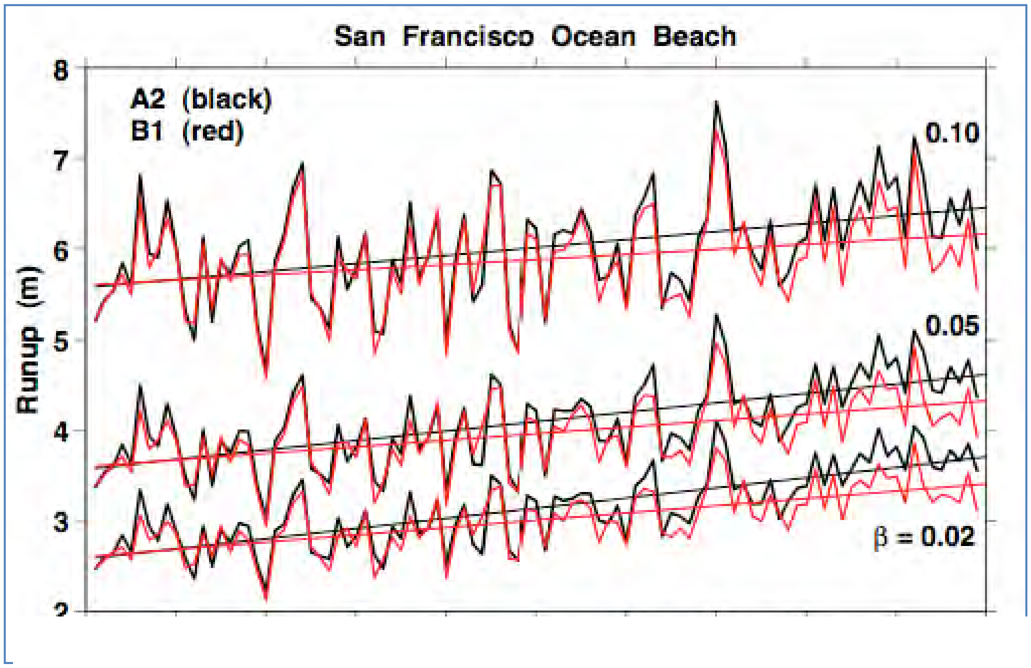

Figure B4.5. Projected Mean Winter (November through March) Runup, San Francisco Ocean Beach

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.

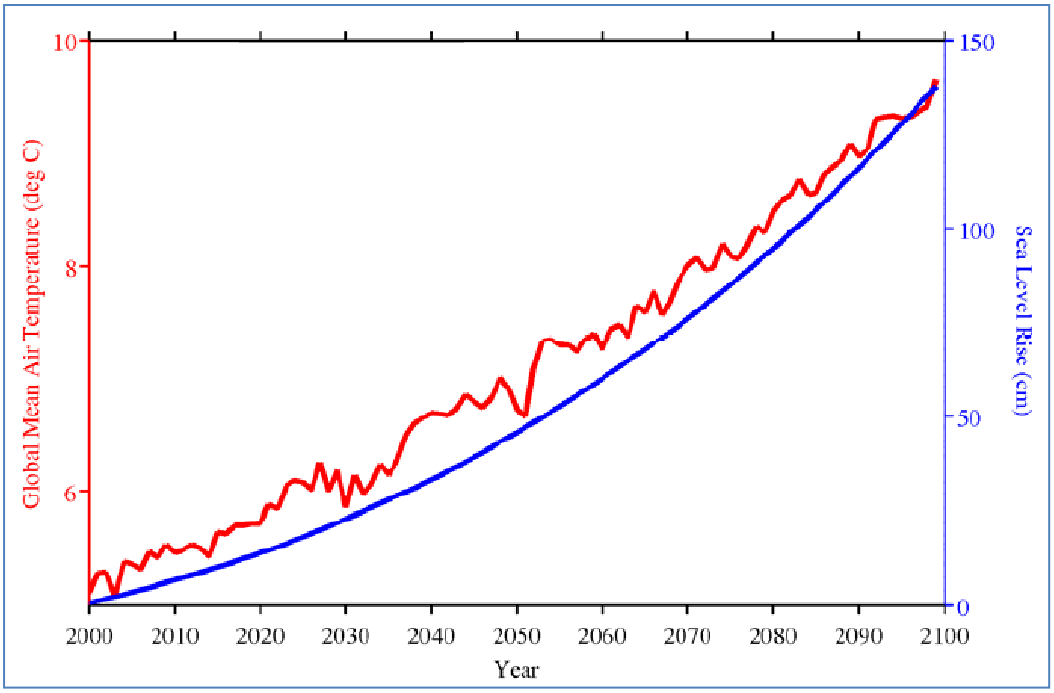

Figure B4.6. Projected Global Mean Surface Air Temperatures (red) from the CCSM3-A2 Global Climate Model and Corresponding Relative Sea Level Rise (blue) from the Rahmstorf model.

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.

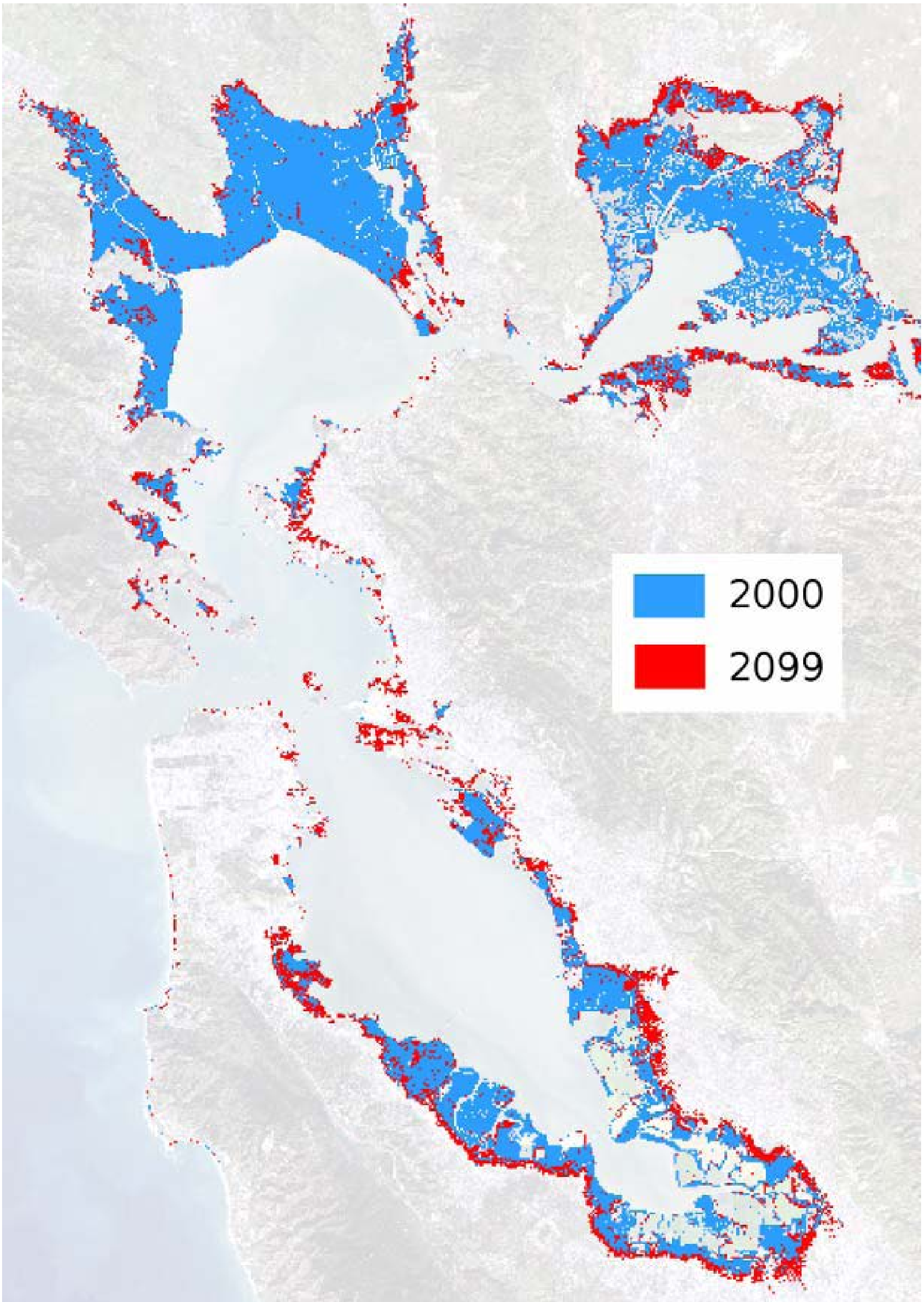

Figure B4.7. Areas Inundated or Vulnerable to Inundation by Average Yearly Bay High Water Levels as of 2000 (Blue) and as of 2099 under a Projected 55-Inch (139-Centimeter) SLR (Red)

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.

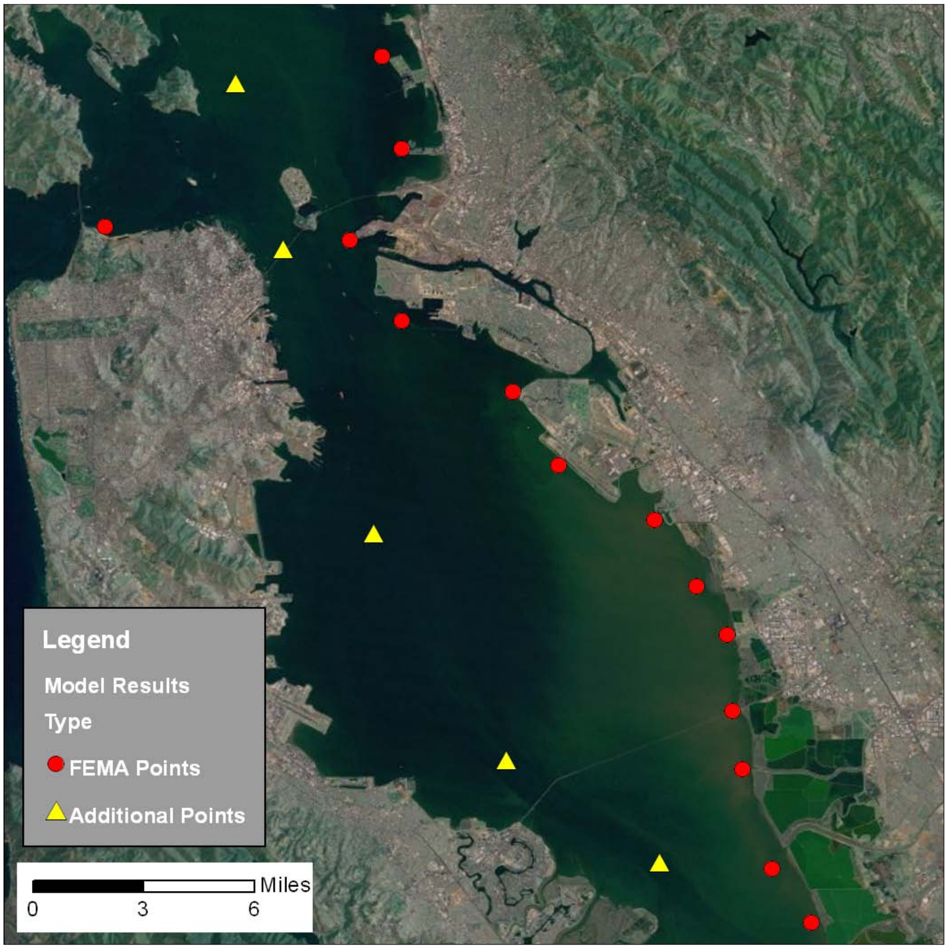

Figure B4.8. DHI and USGS Model Extraction Points within the Project Area

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)

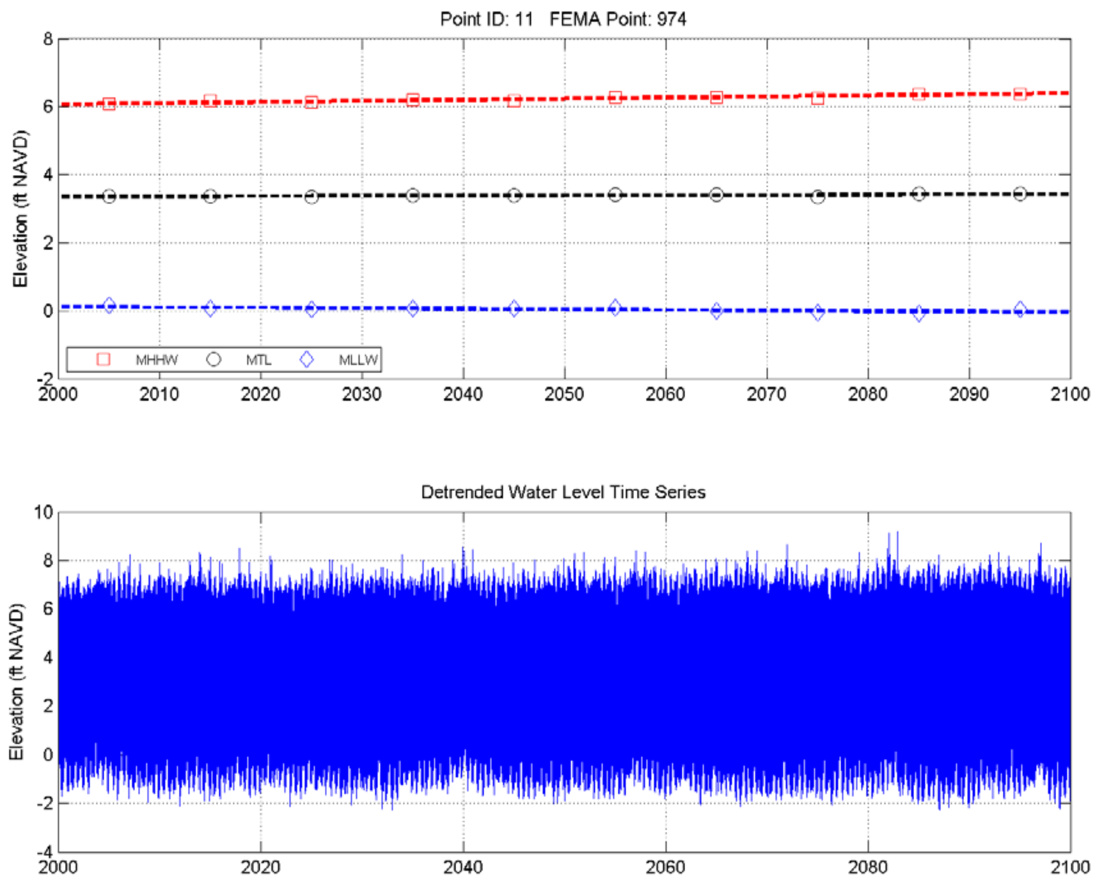

Figure B4.9. Stationarity Analysis and Trends for Sample Model Extraction Point along Alameda County Shoreline

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.

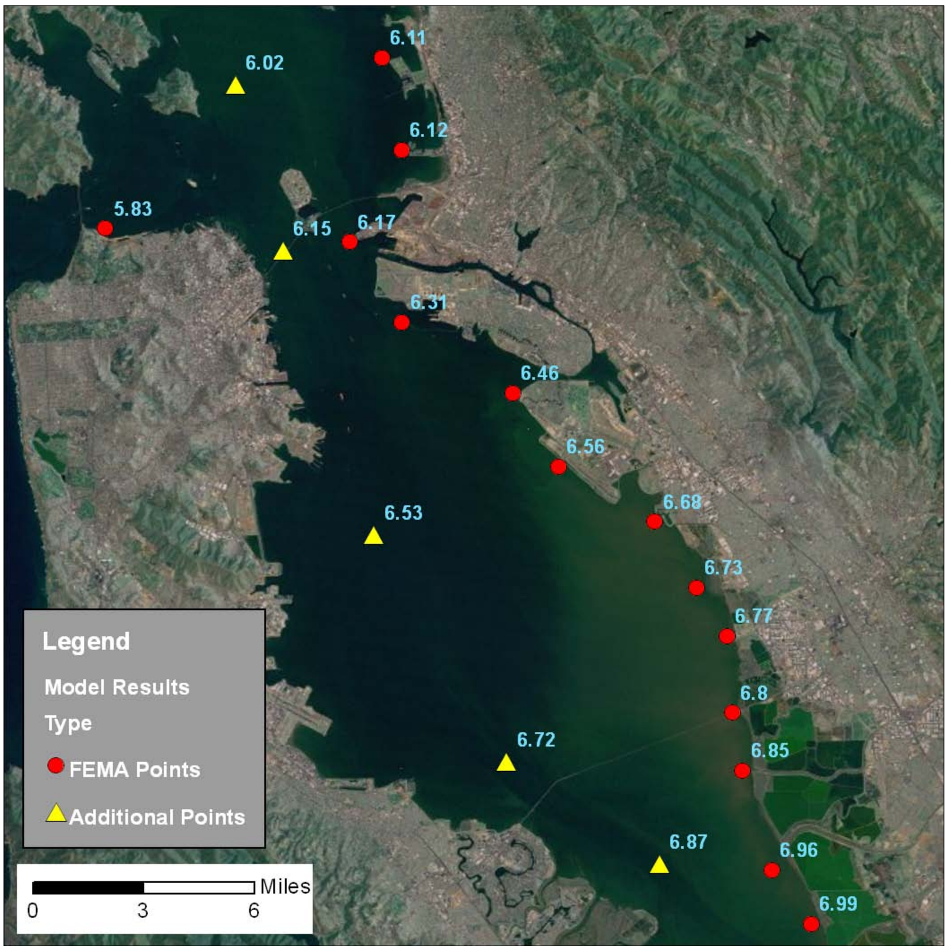

Figure B4.10. Average Daily Tide Elevations (MHHW Tidal Datum) for Existing Conditions Determined from USGS TRIM2D Modeling

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.

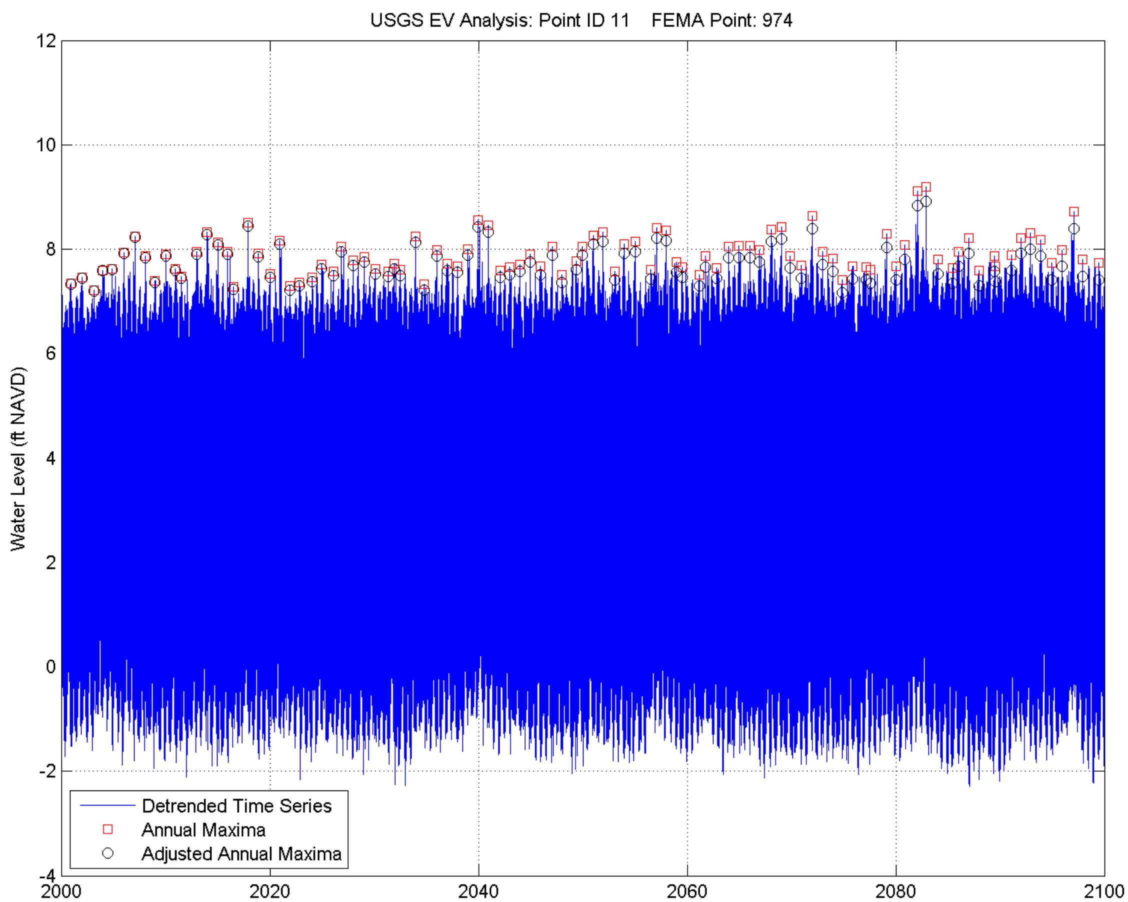

Figure B4.11. Extreme Value Analysis of Annual Maxima for Sample Model Extraction Point along Alameda County Shoreline

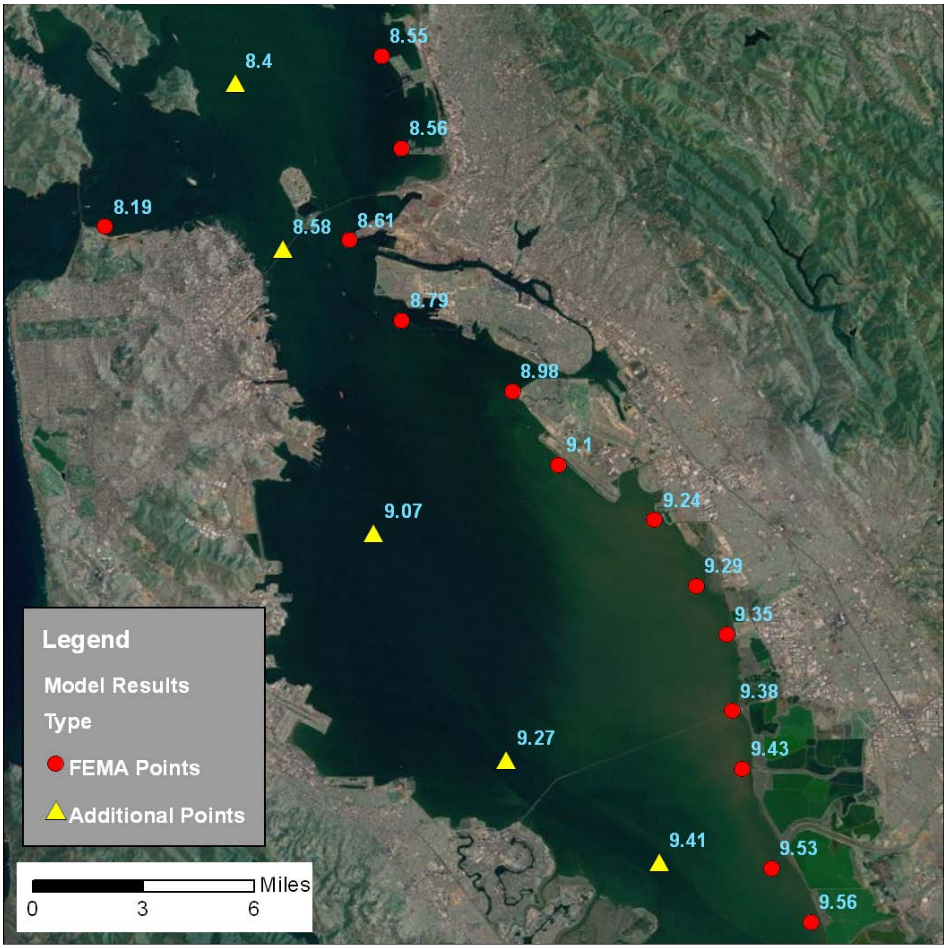

Figure B4.12. Extreme Tide Elevations for Existing Conditions Determined from USGS TRIM2D Modeling

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.

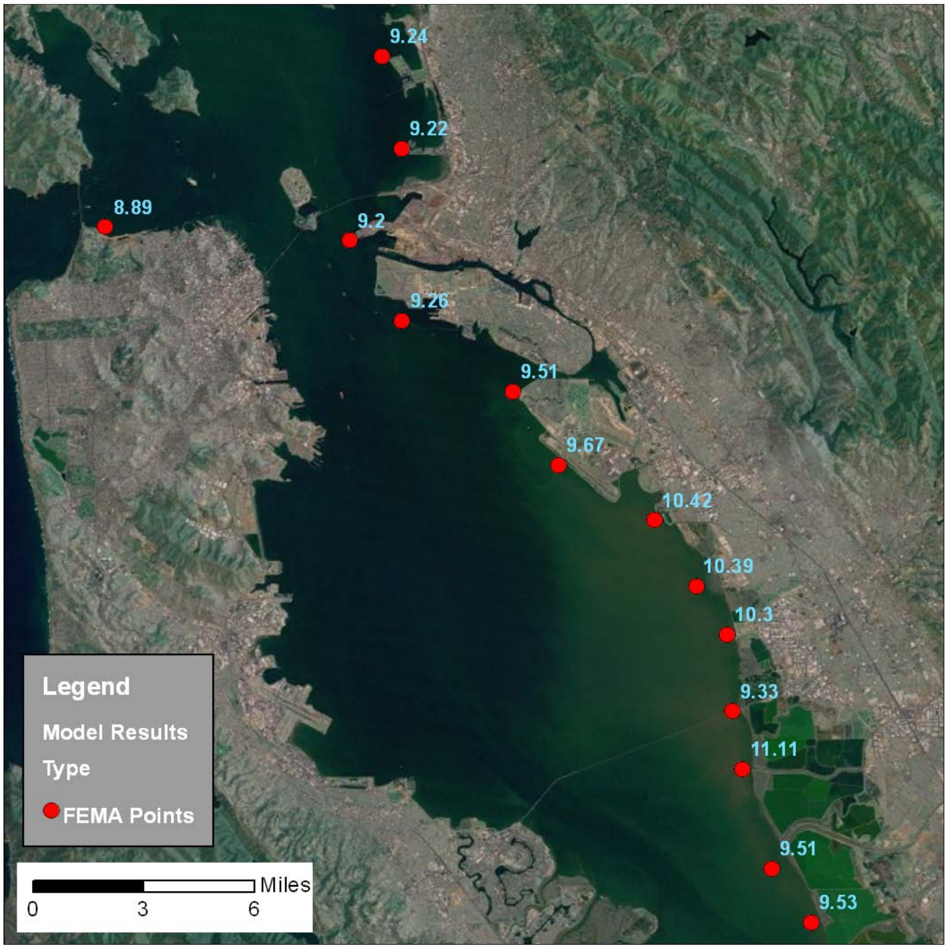

Figure B4.13. Extreme Tide Elevations for Existing Conditions Determined from FEMA MIKE21 Modeling

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.

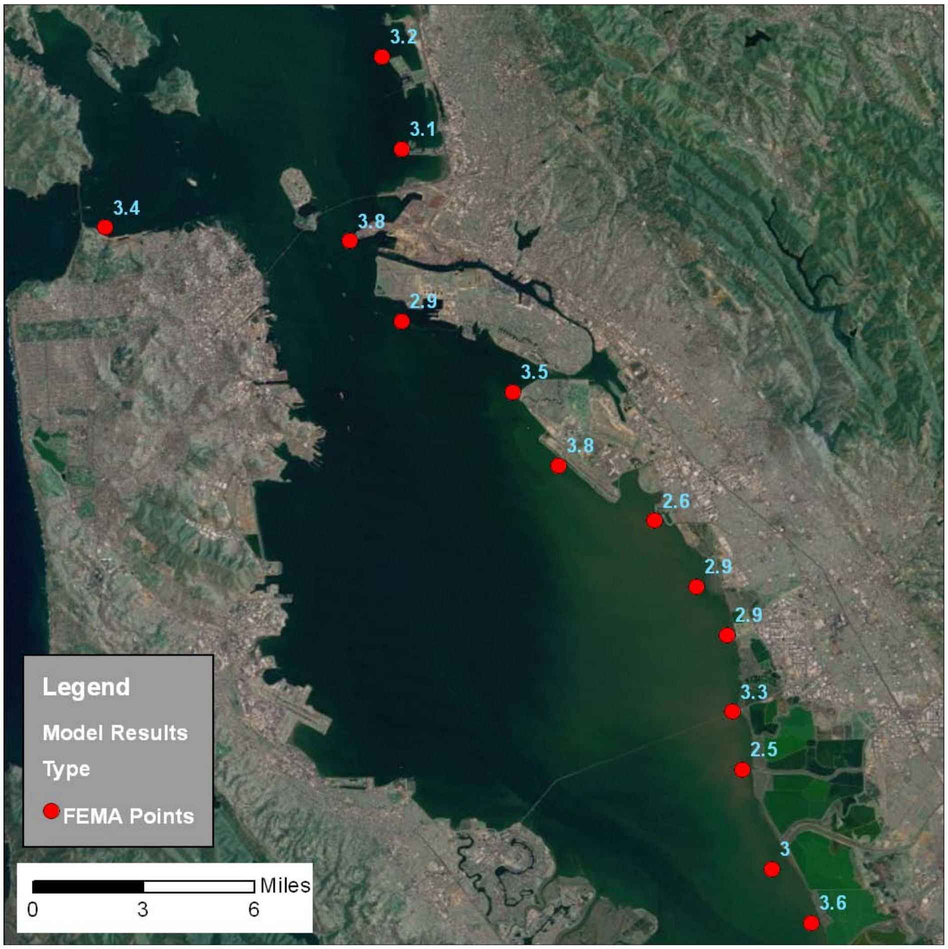

Figure B4.14. Storm Wave Heights for Existing Conditions Determined from DHI MIKE21 Modeling

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.

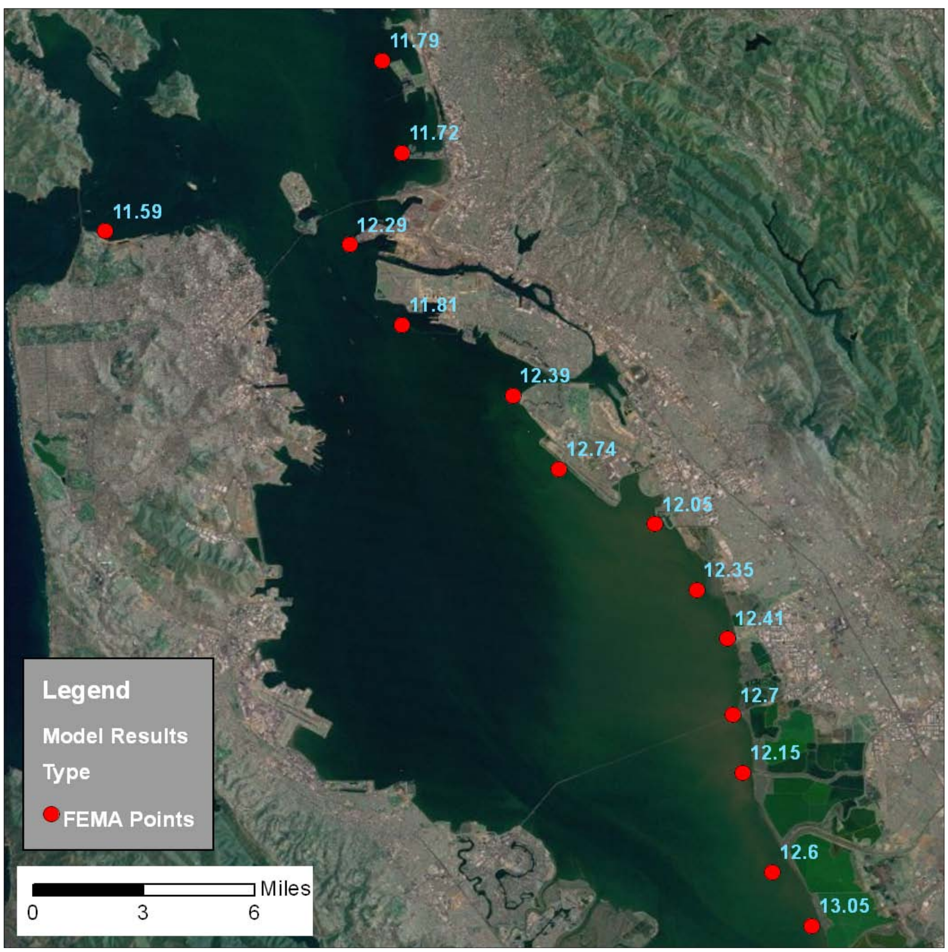

Figure B4.15. Storm Scenario Water Levels with Waves for Existing Conditions

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	

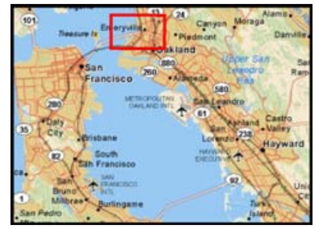
Shoreline Asset "Overtopping" Analysis ***(see Section 4.3.2 for more detail)***	
Proximity of transportation asset to overtopped shoreline asset (distance)	***16" + 100-yr SWEL*** ft Transportation assets that are closer to the shoreline could have a higher likelihood of future inundation
	55" + 100-yr 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)

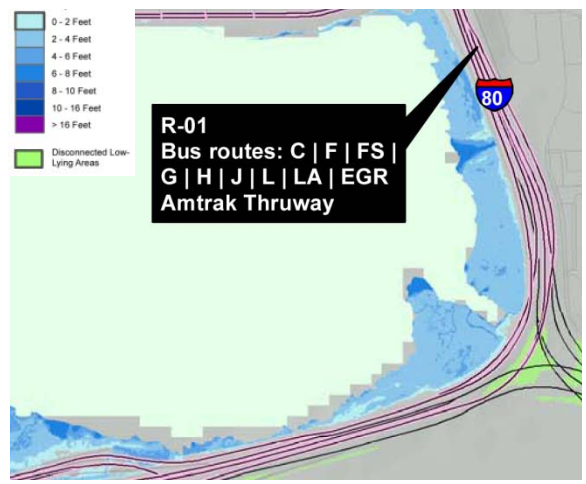
Asset Risk Profile

Interstate 80 (R-01)

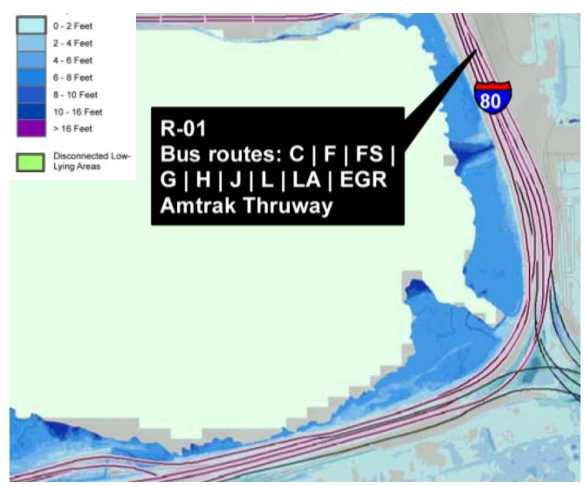


Asset Location / Jurisdiction
Oakland, Emeryville / FHWA, Caltrans
Summary Interstate 80 (I-80) is a freeway that connects Alameda County to the greater region. This profile considers the segment of I-80 between the Bay Bridge Toll Plaza in Oakland and Powell Street in Emeryville. Sensitivity is high (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

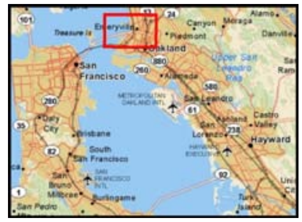
Future Projects
• Install Traffic Operations System • Install bicycle pedestrian path from Bay Bridge to West Grand Avenue • Reconstruct the Bay Bridge Maintenance Complex - South Yard • Construct Tow Services Building and Fueling Station at the Bay Bridge Toll Plaza area • Install median strip landscape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

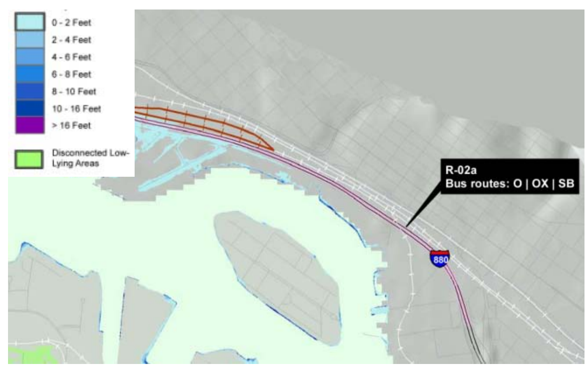


Asset Location / Jurisdiction
Oakland / FHWA, Caltrans

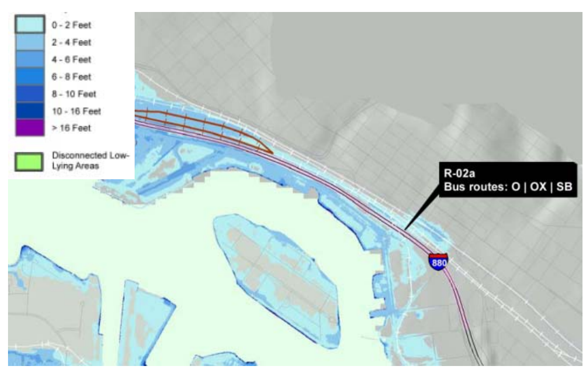
Summary
Interstate 880 (I-880) is a freeway that connects Alameda County to the greater region. The segment of I-880 between Oak Street and 23rd Avenue in Oakland is considered in this profile. Sensitivity is high (due primarily to the high level of use and very high liquefaction potential), while exposure 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



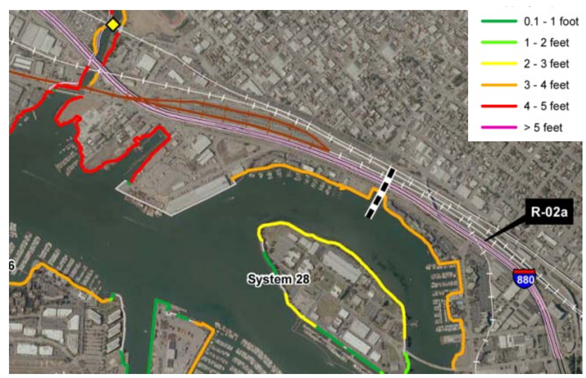
Projected Inundation with 55 inch SLR + 100-yr SWEL

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

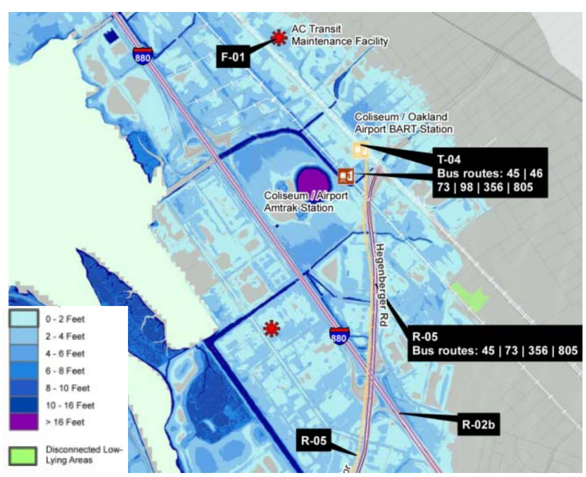
Summary
Interstate 880 (I-880) is a freeway that connects Alameda County to the greater region. The segment of I-880 between High Street and 98th Avenue in Oakland is considered in this profile. Sensitivity is high (due primarily to the high level of use and very high liquefaction potential), while exposure 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

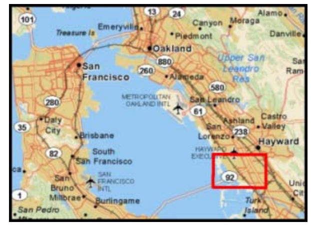
- Widen to accommodate southbound HOV lane from Hegenberger Road to 98th Avenue
- Bridge deck resurfacing and resealing
- Accommodations for BART Oakland Airport Connector

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

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

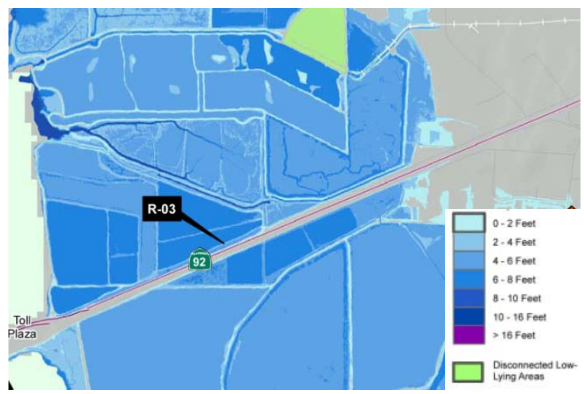
Asset Risk Profile

State Route (SR) 92 (R-03)

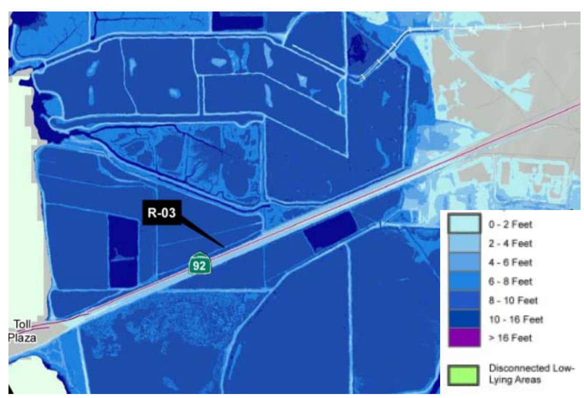


Asset Location / Jurisdiction
Hayward / Caltrans
Summary State Route (SR) 92 is a freeway that connects Alameda County to the greater region. The segment of SR 92 between the San Mateo Bridge toll plaza and Clawiter Road in Hayward is considered in this profile. Sensitivity is low due to moderate level 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

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 16 inch SLR + 100-yr SWEL

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**	

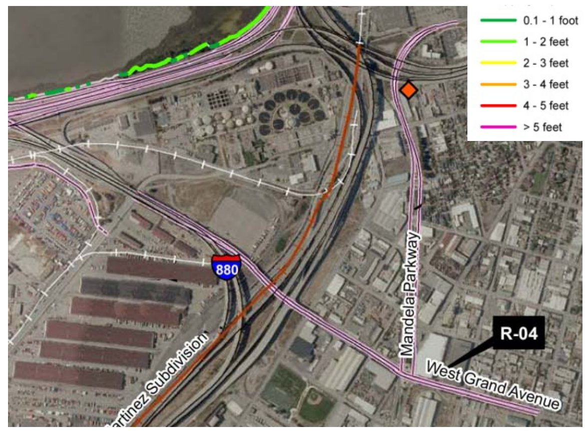
Projected Inundation with 16 inch SLR + 100-yr SWEL

Projected Inundation with 55 inch SLR + 100-yr SWEL

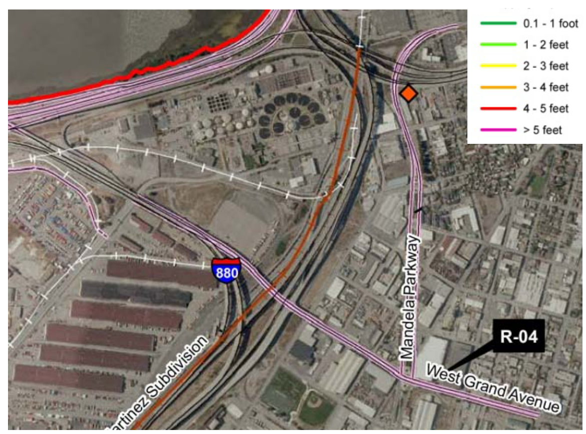
Consequence Rating (out of 5): 3.00	
Capital improvement cost	$22.4 million for portion between Wood and Adeline Streets (3)
Time to rebuild	2 years for portion between Wood and Adeline Streets (1)
Public safety	Oakland Evacuation Route (3)
Economic impact - goods movement	Connects Port of Oakland (seaport) 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

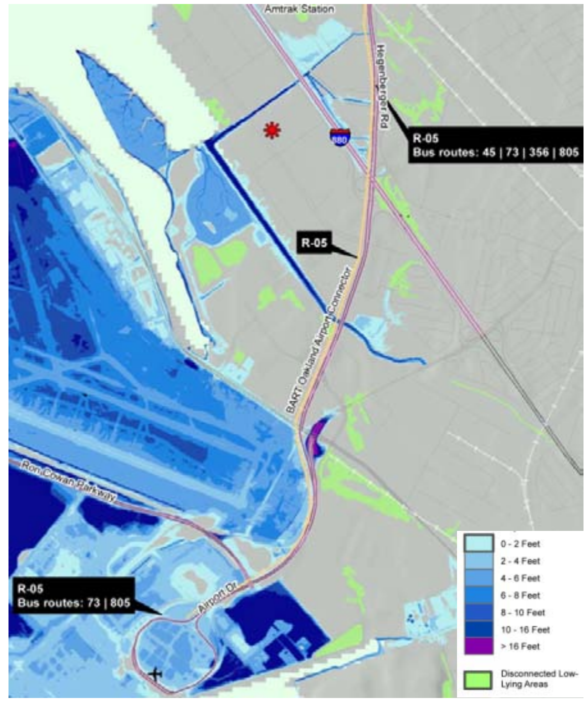
Future Projects	
None	Currently under construction

Asset Risk Profile

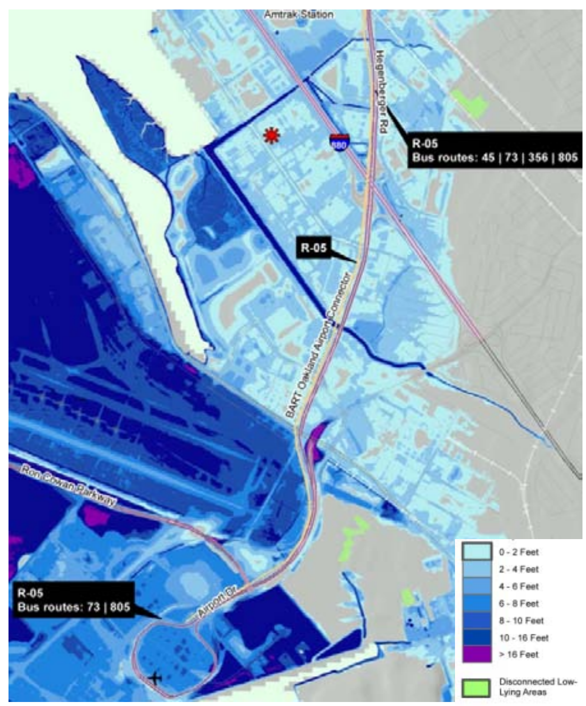
Hegenberger Road

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

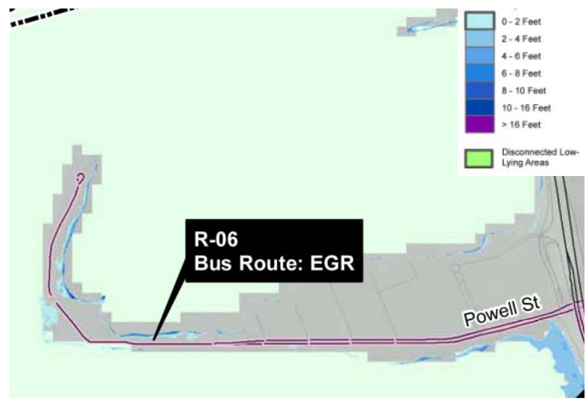
Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

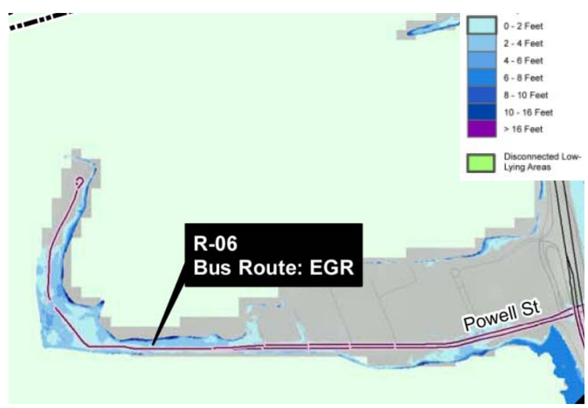
Powell Street (R-06)

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

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

Future Projects
None

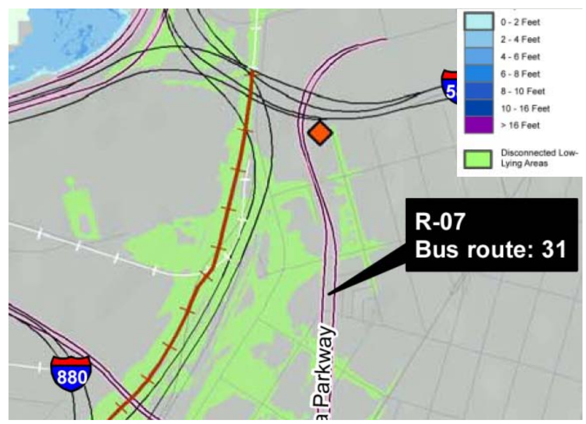
Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

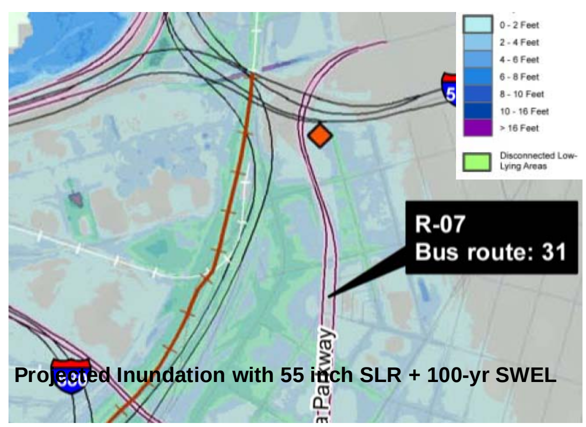
Mandela Parkway (R-07)

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 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	2 ft 4 ft 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

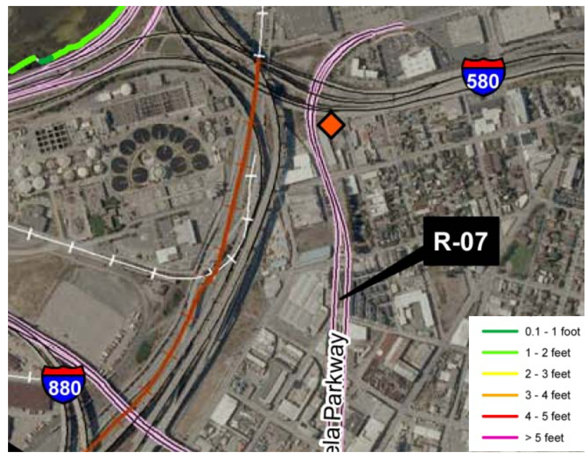


Projected Inundation with 55 inch SLR + 100-yr SWEL

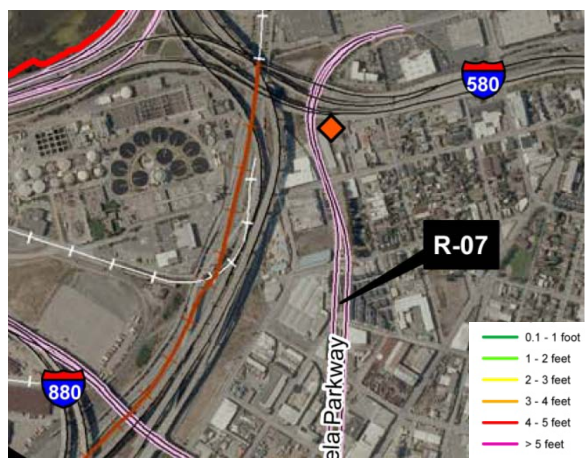
Consequence Rating (out of 5): 1.67	
Capital improvement cost	$15.9 million (between West Grand Avenue and 32nd Street) (1)
Time to rebuild	2 years (between West Grand Avenue and 32nd Street) (1)
Public safety	Not applicable (1)
Economic impact - goods movement	Local street (1)
Economic impact - commuter 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.

Future Projects
None



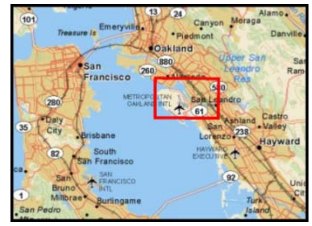
Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



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

Asset Risk Profile

Ron Cowan Parkway (R-08)



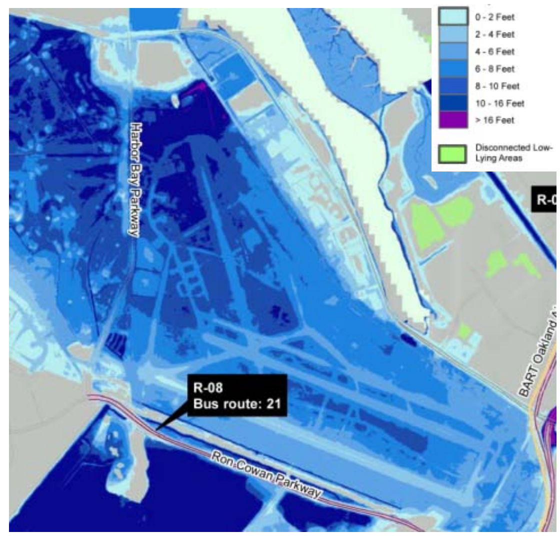
Asset Location / Jurisdiction
Oakland / Port of Oakland

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.

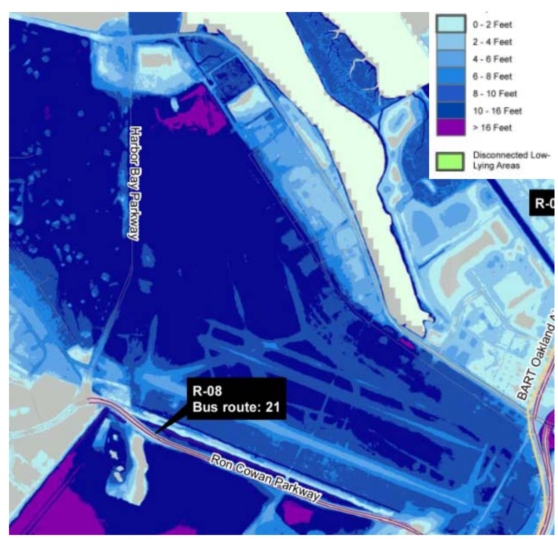
Characteristics:
- Transit routes [AC Transit: 21]
- Bike route

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

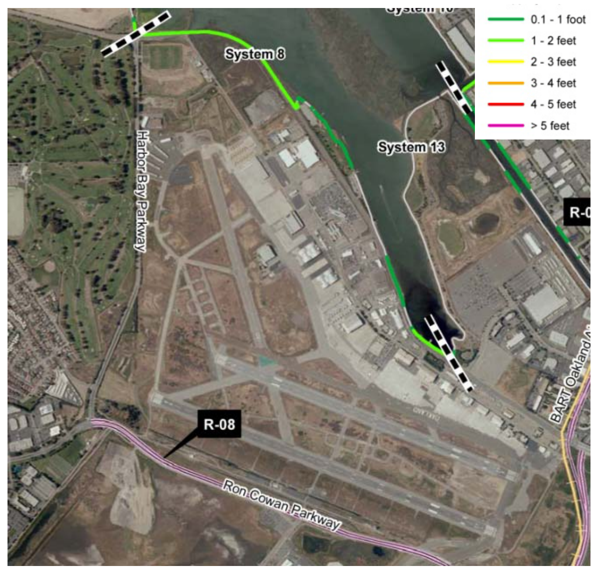


Projected Inundation with 55 inch SLR + 100-yr SWEL

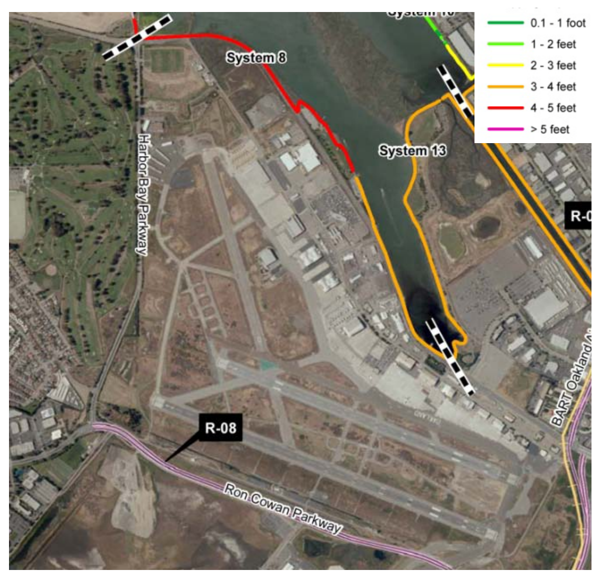
Consequence Rating (out of 5): 3.00	
Capital improvement cost	Data unavailable; professional judgment (includes an underpass) (3)
Time to rebuild	Data unavailable; professional judgment (includes an underpass) (3)
Public safety	Not applicable (1)
Economic impact - goods movement	Connects Port of Oakland (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



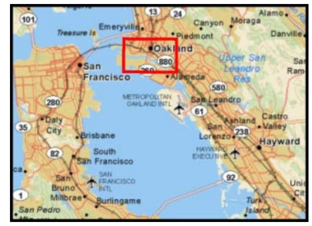
Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



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

Asset Risk Profile

Burma Road (R-09)



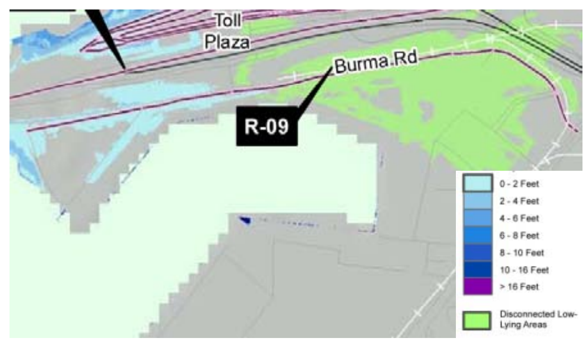
Asset Location / Jurisdiction
Oakland / Port of Oakland

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.

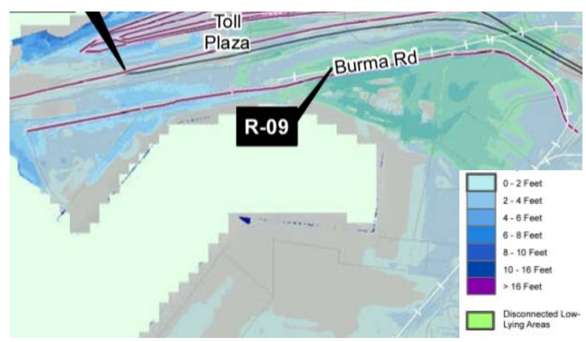
Characteristics:

- 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	



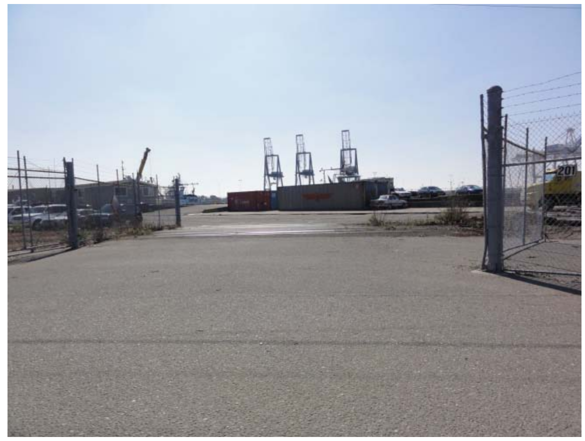
Projected Inundation with 16 inch SLR + 100-yr SWEL

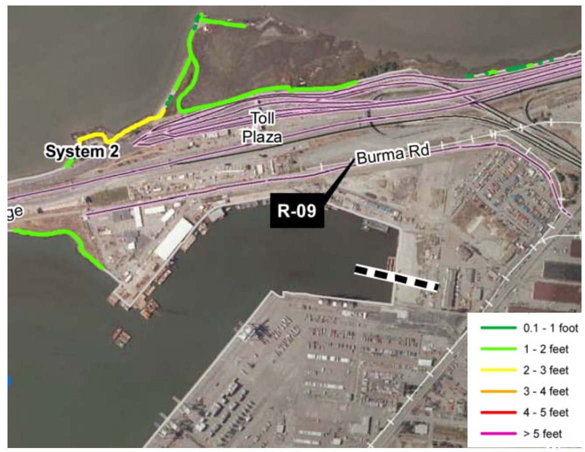


Consequence Rating (out of 5): 1.67	
Capital improvement cost	Data unavailable; professional judgment (local street at grade) (1)
Time to rebuild	Data unavailable; professional judgment (local street at grade) (1)
Public safety	Not applicable (1)
Economic impact - goods movement	Connects Port of Oakland (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	

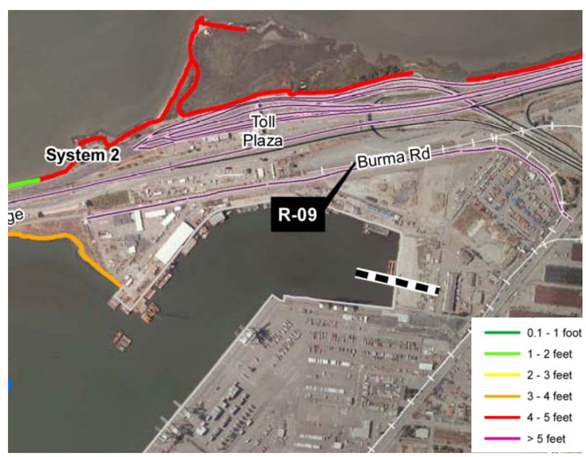
Shoreline Asset "Overtopping" Analysis	
Proximity to Overtopping (distance)	***16" + 100-yr SWEL***
	400ft
	55" + 100-yr SWEL
	400ft
Length Overtopped (% of System)	***16" + 100-yr SWEL***
	10,510 ft (45%)
	55" + 100-yr SWEL
	16,900 ft (72%)
Average Depth of Overtopping	***16" + 100-yr SWEL***
	1.7 ft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





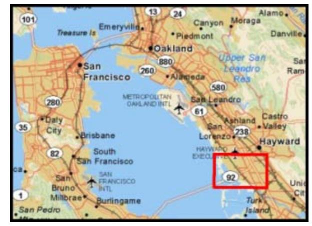
Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



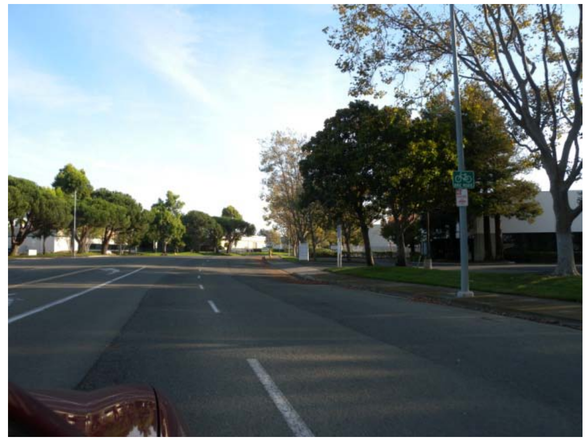
Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

Asset Risk Profile

Cabot Boulevard (R-10)

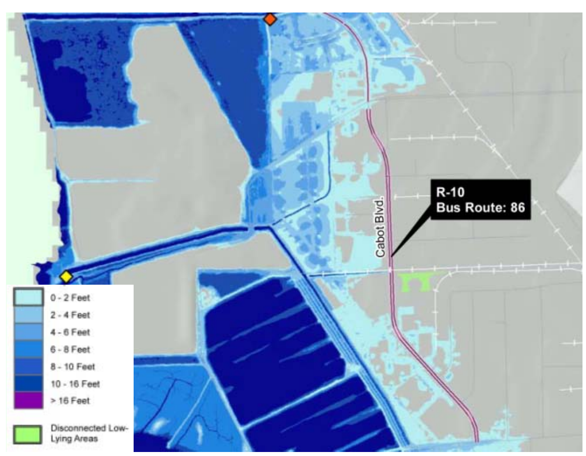


Asset Location / Jurisdiction Hayward / City of Hayward	
Summary Cabot Boulevard is a local street in the industrial area near the Hayward shoreline. In the future, an extension of the street and interchange with SR 92 are planned. Sensitivity is low (due to relatively low level of use and annual O&M 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	

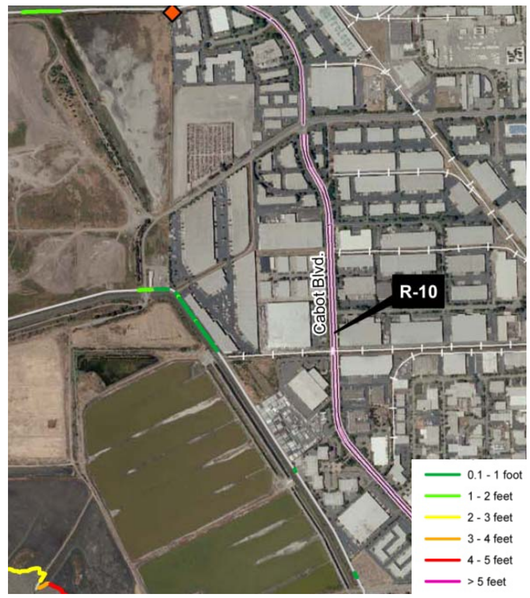
Projected Inundation with 16 inch SLR + 100-yr SWEL



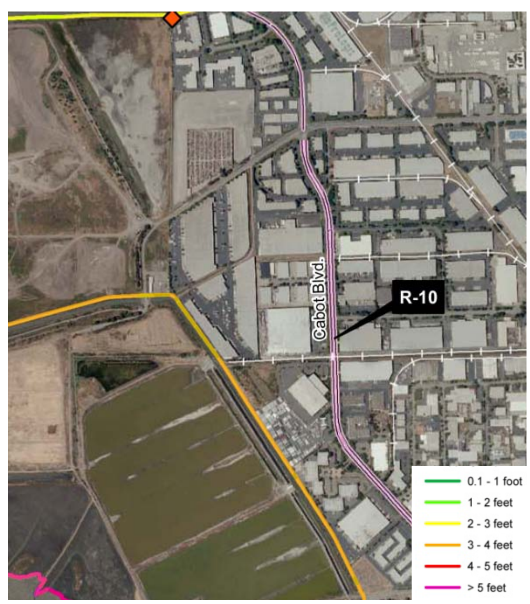
Consequence Rating (out of 5): 2.67	
Capital improvement cost	$64.7 million (5)
Time to rebuild	2+ years (includes proposed interchange) (3)
Public safety	Not applicable (1)
Economic impact - goods movement	Local street (1)
Economic impact - commuter route	946 daily transit riders (3)
Socio-economic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



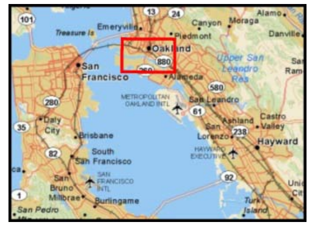
Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



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

Asset Risk Profile

Webster and Posey Tubes (R-11)

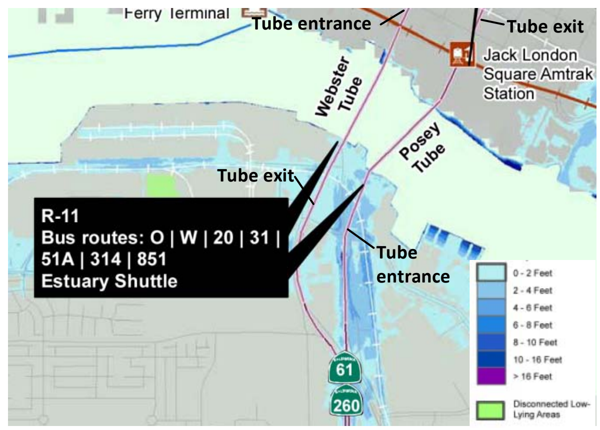


Asset Location / Jurisdiction Oakland – Alameda / Caltrans	
Summary The Webster and Posey Tubes are underwater tunnels that connect Alameda and Oakland and compose State Route 260, though they are signed as State Route 61. Both assets rank medium for sensitivity. Exposure for Webster Tube is medium (due 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]	

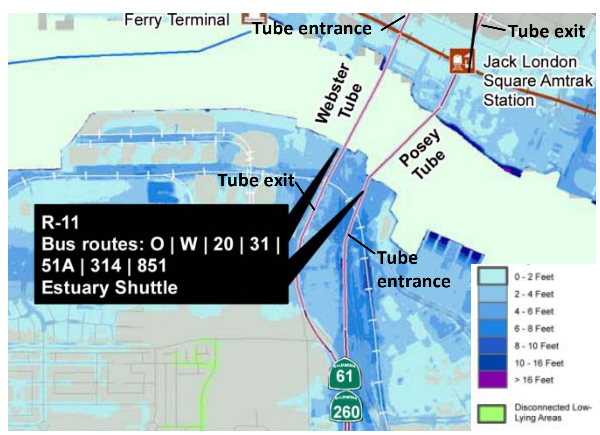
	Posey Tube	Webster Tube
Sensitivity:	**Medium**	**Medium**
Year Built	1927	1963
Level of Use		
Peak Hour	1,850	1,850
AADT	22,300	22,300
AADTT	535	535
Seismic Retrofit	Yes (2004; liquefaction potential was accounted for)	Yes (2005; liquefaction potential was accounted for)
Annual O&M	$83,300	$72,800
Liquefaction 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



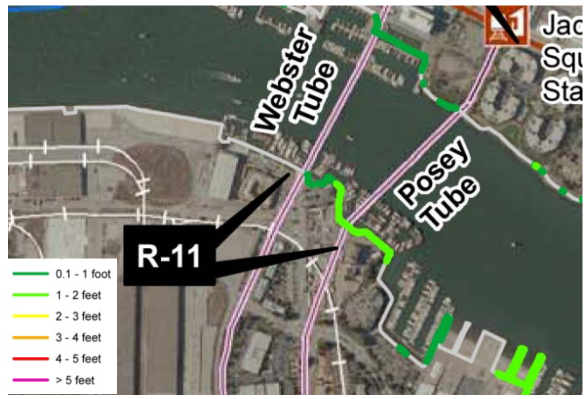
Projected Inundation with 55 inch SLR + 100-yr SWEL

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

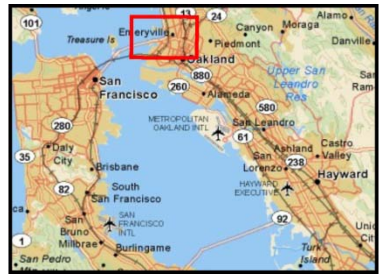


Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL

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	

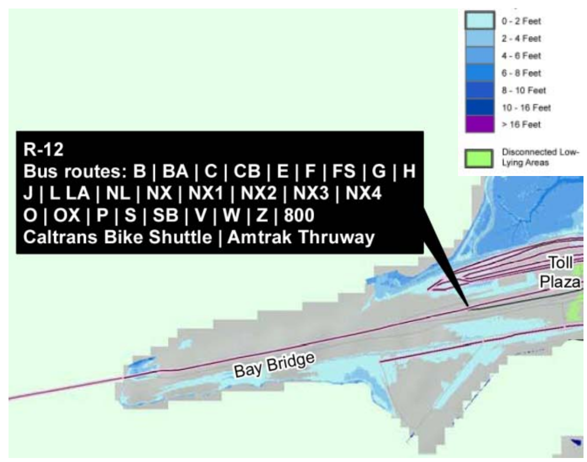
Summary

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.

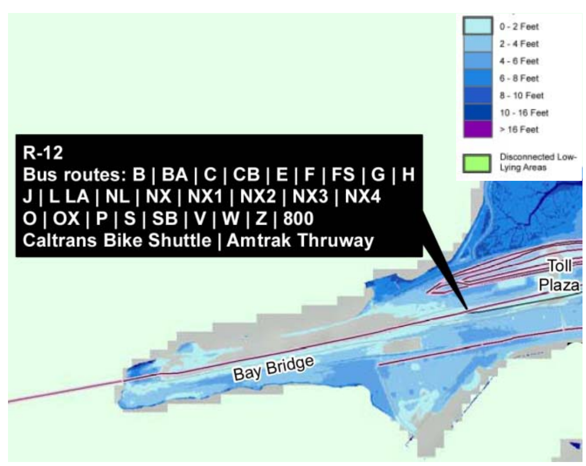
Characteristics:

- 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



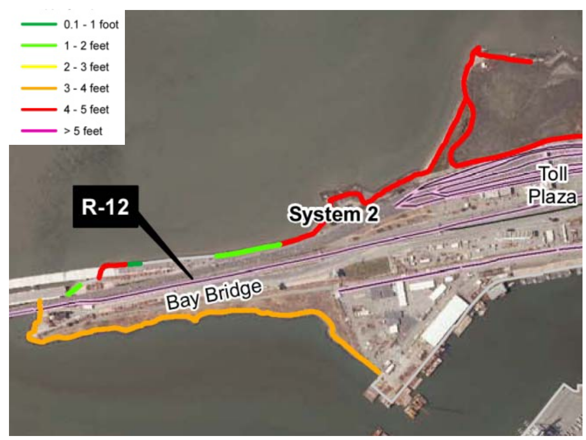
Projected Inundation with 55 inch SLR + 100-yr SWEL

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

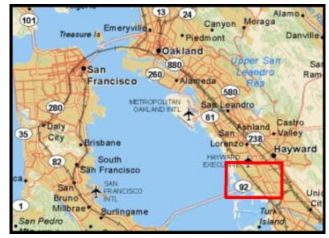
Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



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

Asset Risk Profile

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

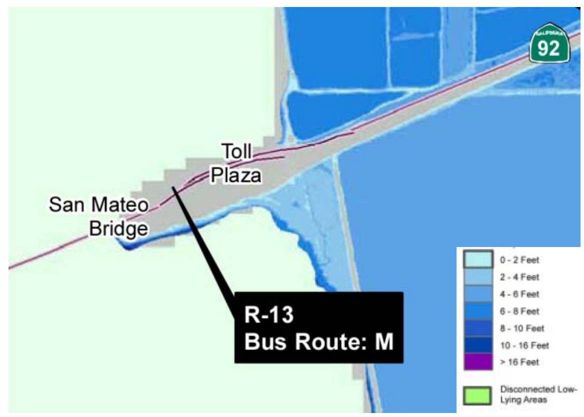


Asset Location / Jurisdiction
Hayward / FHWA, Caltrans

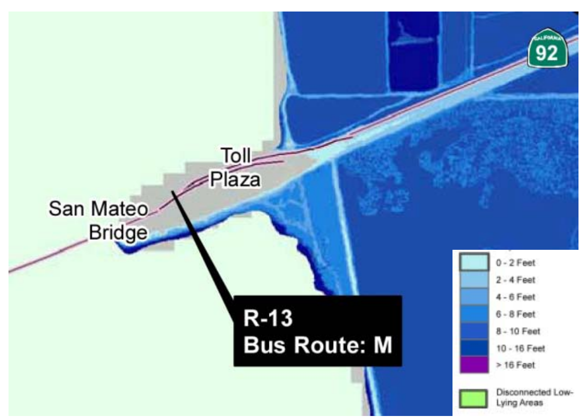
Summary
The San Mateo Bridge (SR 92) connects Alameda County with San Mateo County. This profile considers the toll plaza and the approach to the bridge. Sensitivity is medium (due to its relatively moderate level of use and very high liquefaction potential), while exposure is low (due to inundation 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

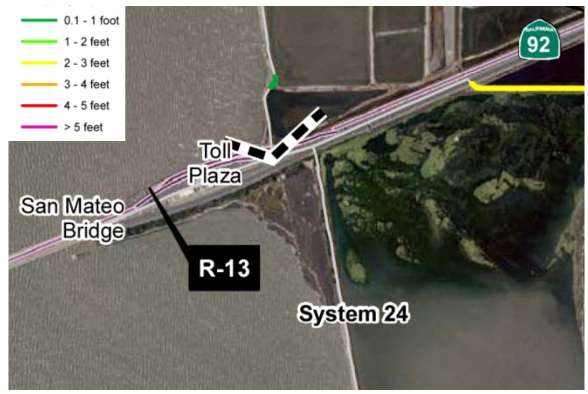


Projected Inundation with 55 inch SLR + 100-yr SWEL

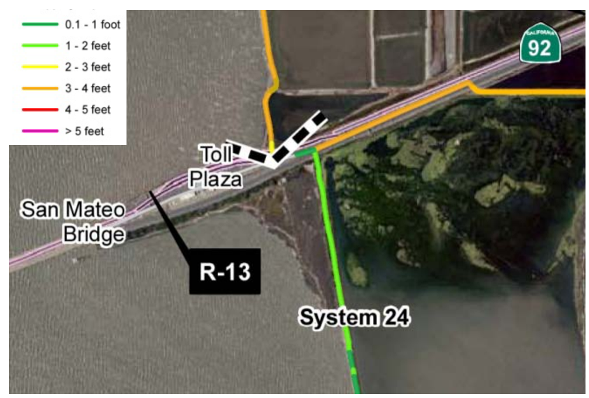
Consequence Rating (out of 5): 3.67	
Capital improvement cost	$560 million (5)
Time to rebuild	84 months (5)
Public safety	Freeway (3)
Economic impact - goods movement	1,806 AADTT (3)
Economic impact - commuter route	Freeway (and 491 daily transit riders) (5)
Socio-economic impact	Pass-through transit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



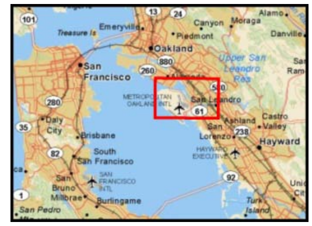
Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



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

Asset Risk Profile

Bay Farm Island Bridge (R-14)



Asset Location / Jurisdiction

Alameda / Caltrans

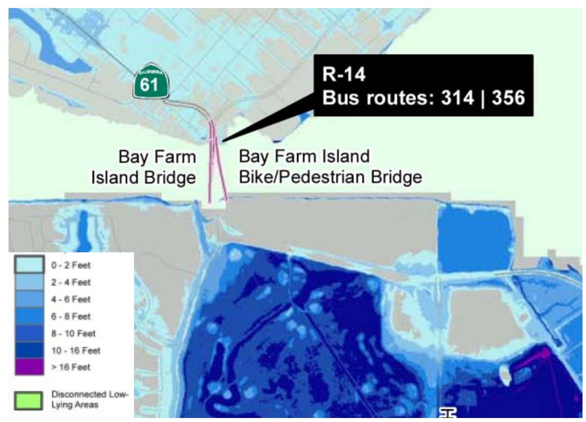
Summary

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.

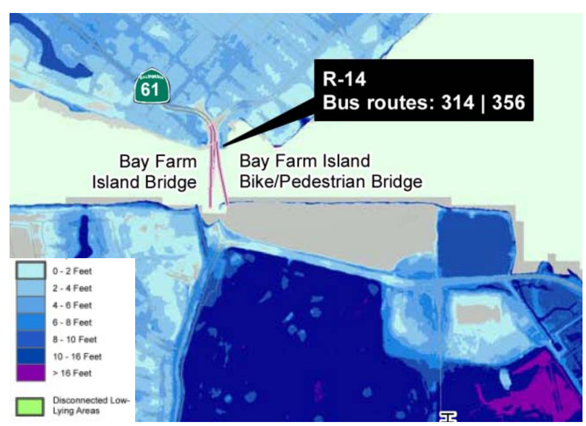
Characteristics:

- 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

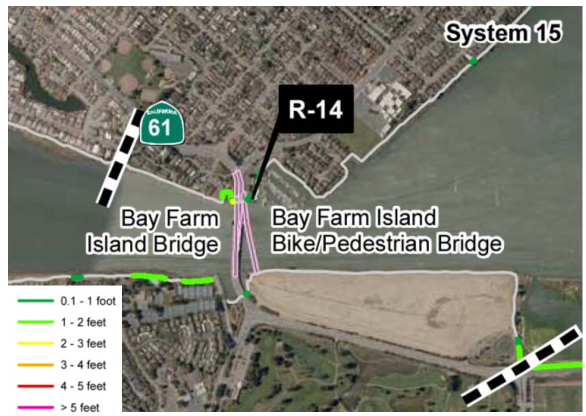


Projected Inundation with 55 inch SLR + 100-yr SWEL

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

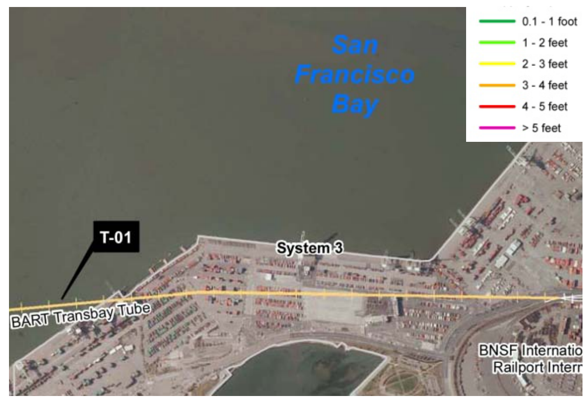
Projected Inundation with 16 inch SLR + 100-yr SWEL

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



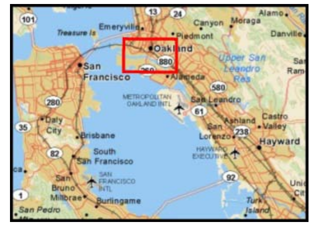
Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL

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

Asset Risk Profile

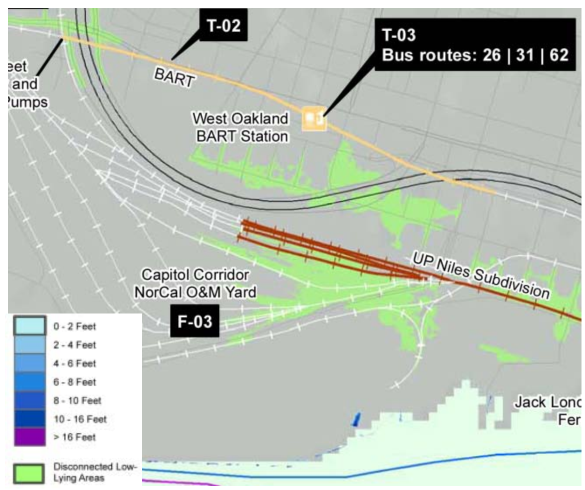
Elevated BART Line between Transbay Tube and Oakland Wye (T-02)

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	

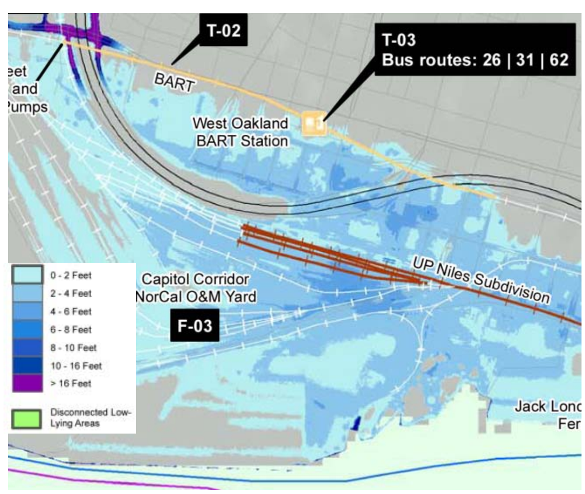


Sensitivity	
Information unavailable in project timeframe.	
Liquefaction Susceptibility	Medium
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW 16" + 100-yr SWEL 16" + 100-yr SWEL + wind waves	0 ft 0 ft YES
55" + MHHW 55" + 100-yr SWEL 55" + 100-yr SWEL + wind waves	0 ft 24 ft* YES
Inadequate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

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



Projected Inundation with 16 inch SLR + 100-yr SWEL

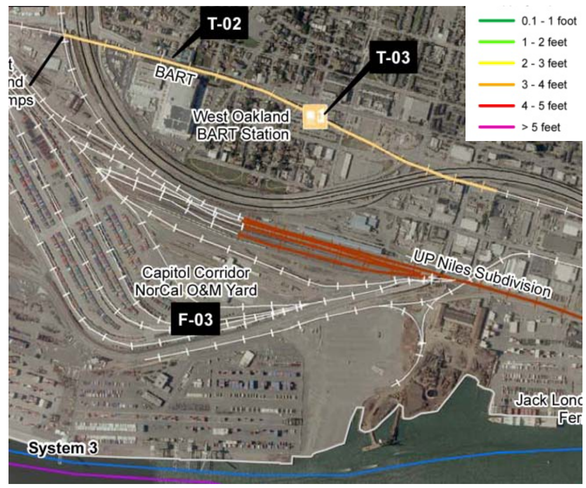


Projected Inundation with 55 inch SLR + 100-yr SWEL

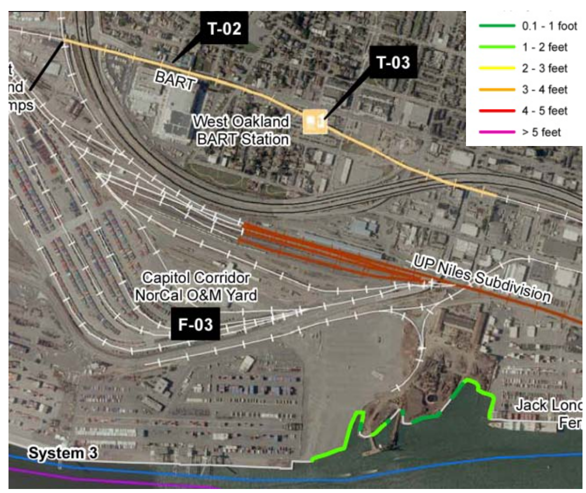
Consequence Rating (out of 5): 3.33	
Capital improvement cost	Likely $20-50 million excluding station (3)
Time to rebuild	Likely within 5 years (3)
Public safety	Regional significance, alternative to Bay Bridge (5)
Economic impact - goods movement	Not applicable (1)
Economic impact - commuter route	169,011 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



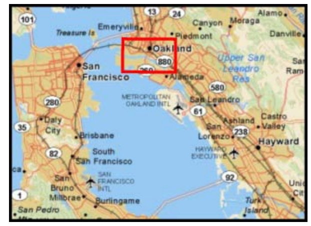
Projected Overtopping Depth at 16 inch SLR + 100yr SWEL



Projected Overtopping Depth at 55 inch SLR + 100yr SWEL

Asset Risk Profile

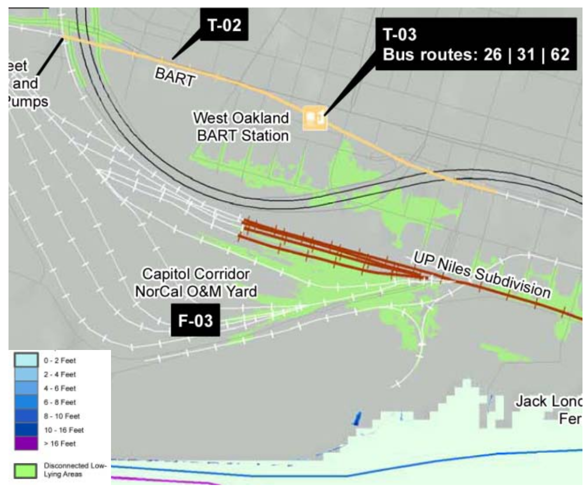
West Oakland BART Station (T-03)



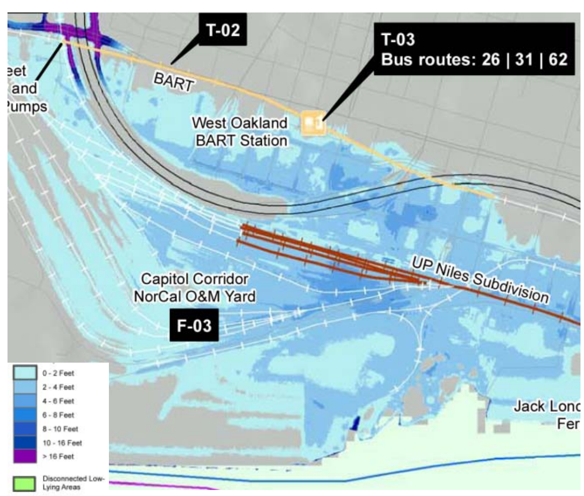
Asset Location / Jurisdiction Oakland / BART	
Summary West Oakland BART Station is a transit facility serving West Oakland neighborhoods and includes bus transfer and parking facilities. Due to lack of data, this asset was not rated with respect to sensitivity. Exposure is rated low, due to inundation 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 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 0 ft* 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

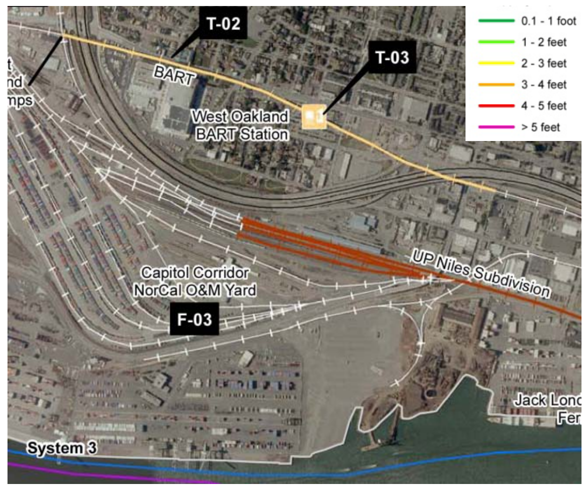


Projected Inundation with 55 inch SLR + 100-yr SWEL

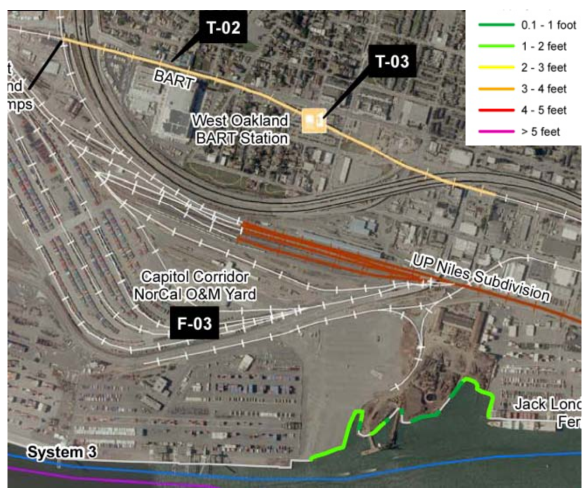
Consequence Rating (out of 5): 3.33	
Capital improvement cost	West / Dublin Pleasanton Station cost $106 million (5)
Time to rebuild	West Dublin / Pleasanton Station construction planned at 3 years (3)
Public safety	Minor consequence (1)
Economic impact - goods movement	Not applicable (1)
Economic impact - 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



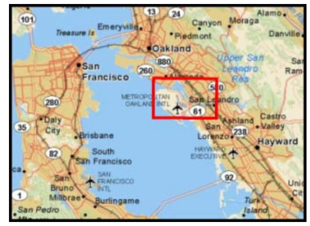
Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



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

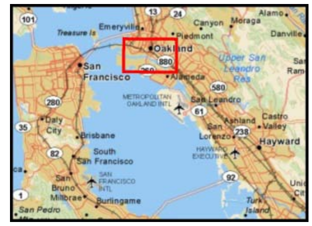
Oakland Jack London Square Amtrak Station (T-05)

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

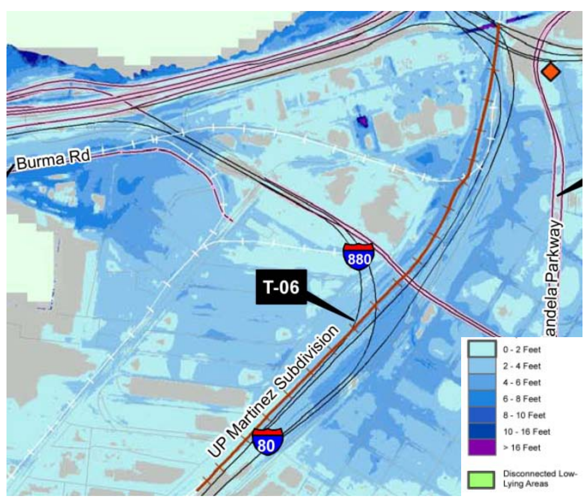
Asset Risk Profile

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

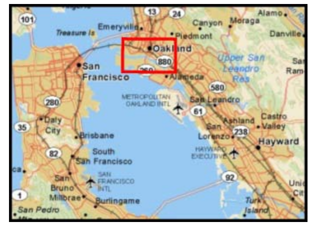
Projected Overtopping Depth at 55 inch SLR + 100-yr SWEL

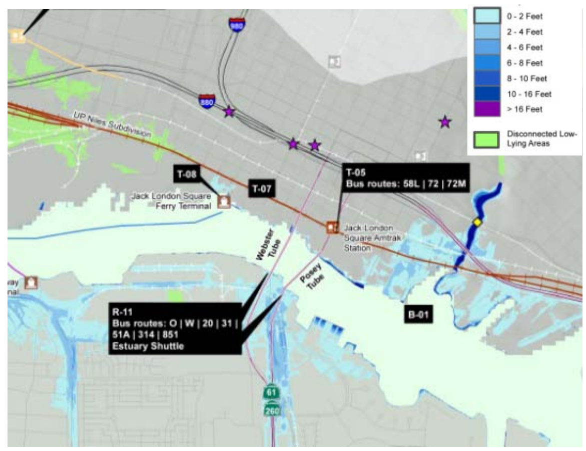
Asset Risk Profile

UP Niles Subdivision (T-07)

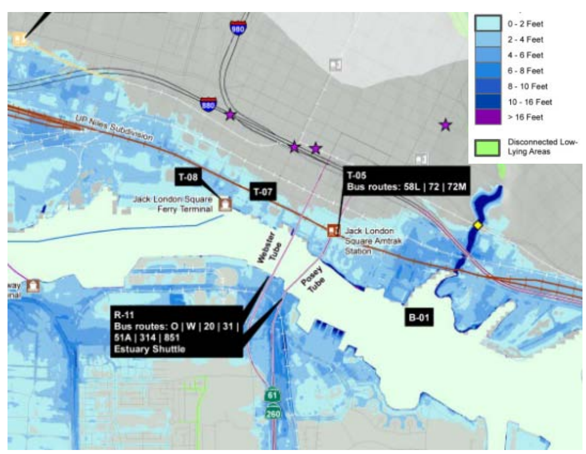
Asset Location / Jurisdiction Oakland / Union Pacific Railroad
Summary The Niles Subdivision is owned by Union Pacific Railroad and serves passenger and freight operations. This profile considers the segment between the Magnolia Crossover and East Oakland Yard in Oakland. Due to lack of data, this asset 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

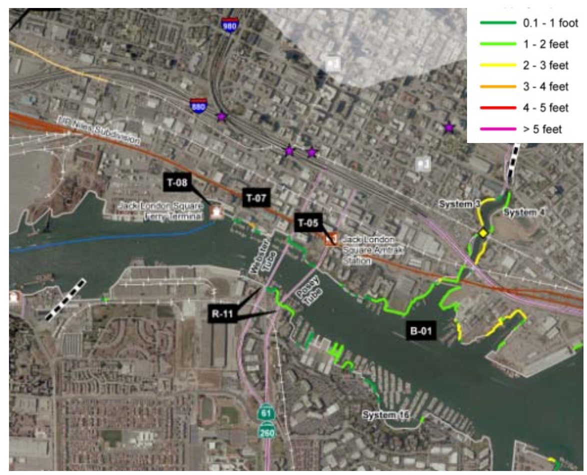


Projected Inundation with 55 inch SLR + 100-yr SWEL

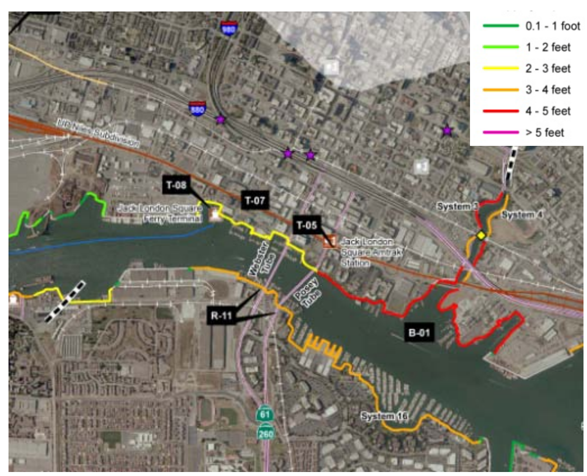
Consequence Rating (out of 5): 3.00	
Capital improvement cost	At-grade railroad plus bridge over Lake Merritt inlet to cost at least $50 million (5)
Time to rebuild	At-grade, plus bridge over Lake Merritt inlet, likely within 5 years (3)
Public safety	Minor consequence (1)
Economic impact - goods movement	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

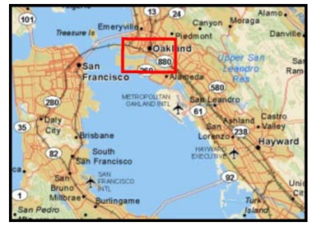


Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



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

Jack London Square Ferry Terminal (T-08)



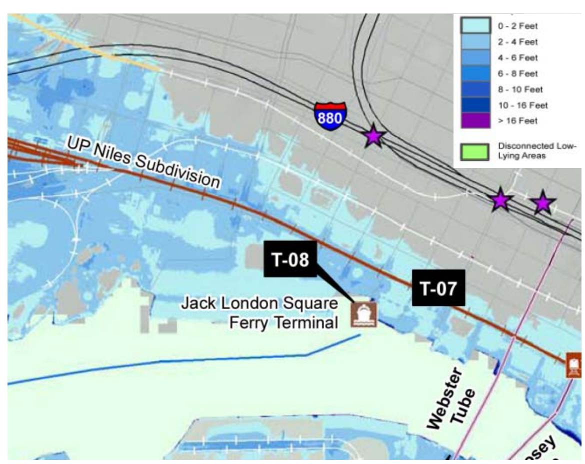
Asset Location / Jurisdiction
Oakland / WETA

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

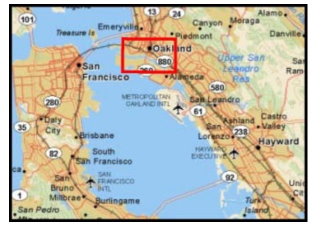
Asset Risk Profile

Alameda Gateway Ferry Terminal (T-09)

Asset Location / Jurisdiction
Oakland / WETA

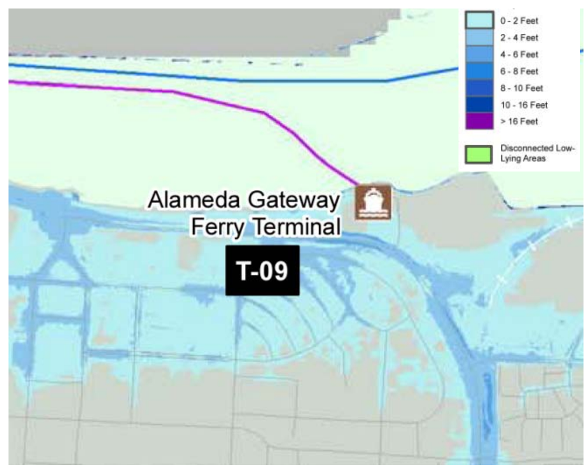
Summary
The Alameda Gateway Ferry Terminal facilitates ferry service between Alameda and the City and County of San Francisco, and includes parking, bicycle and ADA access. Sensitivity is medium (due to 'fair' condition), as is exposure (due to inundation under the 55" + 100-yr SWEL SLR scenario). No 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]

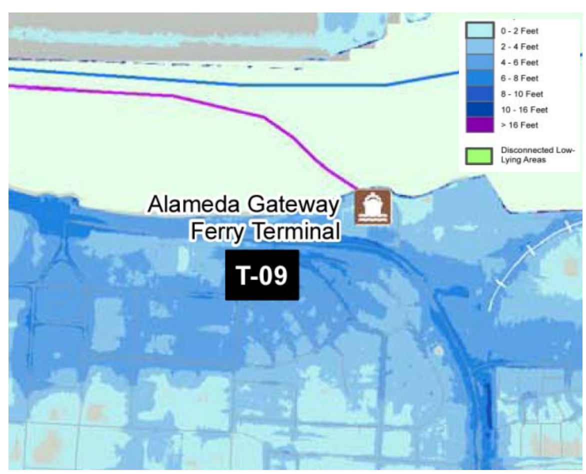


Sensitivity: Medium	
Built	ca. 1991
Level of Use	13 ferries/day 239,000 trips/year
Seismic Retrofit	No
Annual O&M	$5,000-$10,000
Liquefaction Susceptibility	Very High
Exposure: Medium	
Maximum Inundation Depths	
16" + MHHW 16" + 100-yr SWEL 16" + 100-yr SWEL + wind waves	0 ft 0 ft* YES
55" + MHHW 55"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

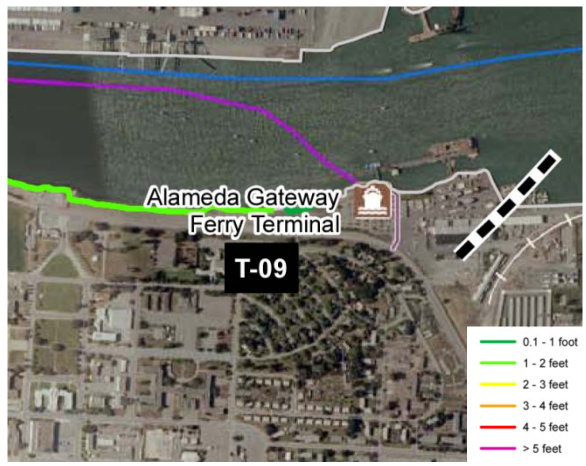


Projected Inundation with 55 inch SLR + 100-yr SWEL

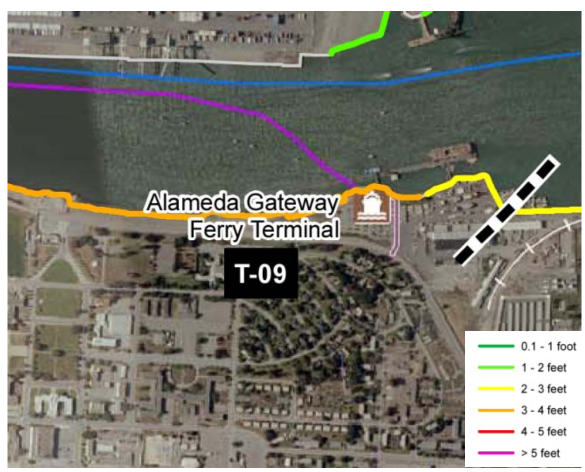
Consequence Rating (out of 5): 1.67	
Capital improvement cost	$15-20 million for total replacement (1)
Time to rebuild	18-24 months from start of construction (1)
Public safety	Critical to immediate disaster response and recovery (3)
Economic impact - goods movement	Not applicable (1)
Economic impact - 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

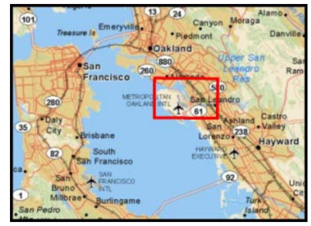
AC Transit Maintenance Facility (1100 Seminary Avenue) (F-01)

Asset Location / Jurisdiction
Oakland / AC Transit

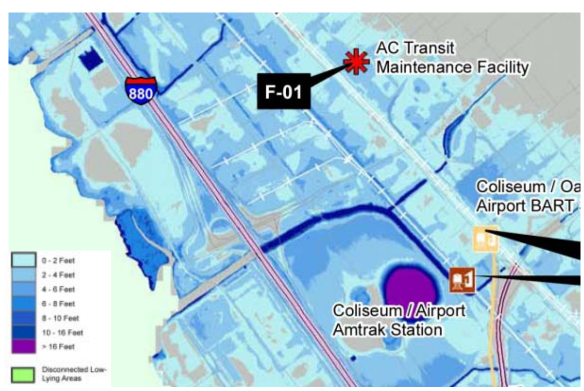
Summary
AC Transit operates a bus maintenance and storage facility at 1100 Seminary Avenue in Oakland. Due to lack of data, this asset was not rated with respect to sensitivity. Exposure is rated medium, due to inundation under the 55" + 100-yr SWEL SLR scenario. AC Transit operates other maintenance 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



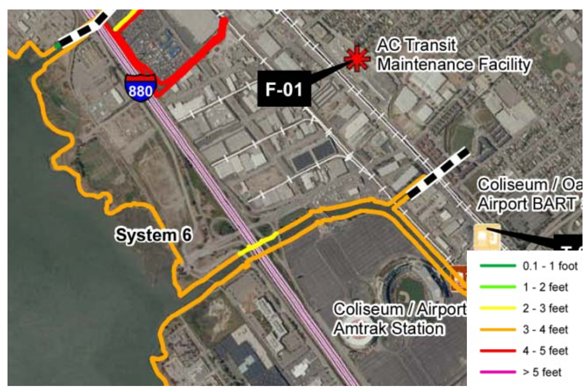
Projected Inundation with 55 inch SLR + 100-yr SWEL

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

Future Projects
None

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



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

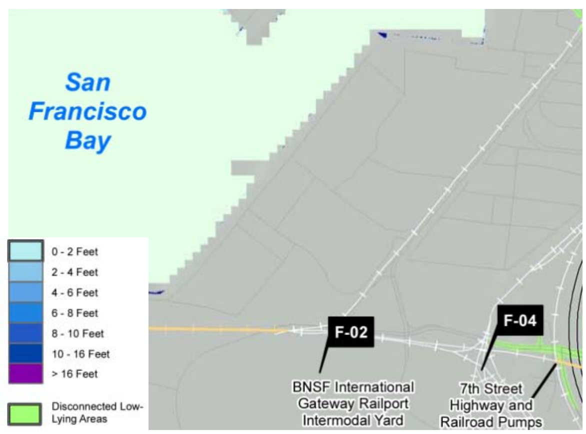
BNSF International Gateway Intermodal Yard (F-02)

Asset Location / Jurisdiction
Oakland / BNSF Railway

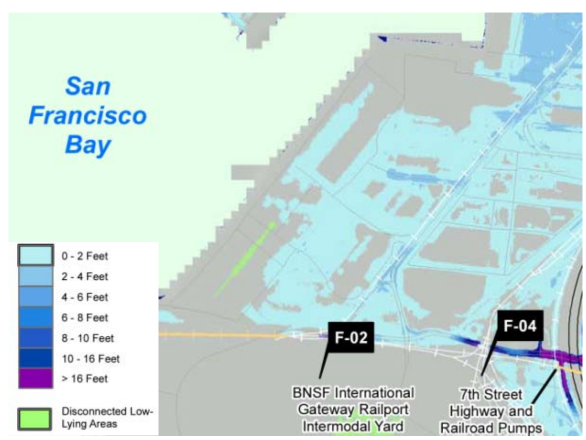
Summary
BNSF Railway operates an intermodal shipping facility at the Port of Oakland, adjoining the Union Pacific Niles Subdivision. Due to lack of data, this asset was not rated with respect to sensitivity. Exposure is rated low, due to inundation under only 100-year SWEL + wind waves for both the 16" 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

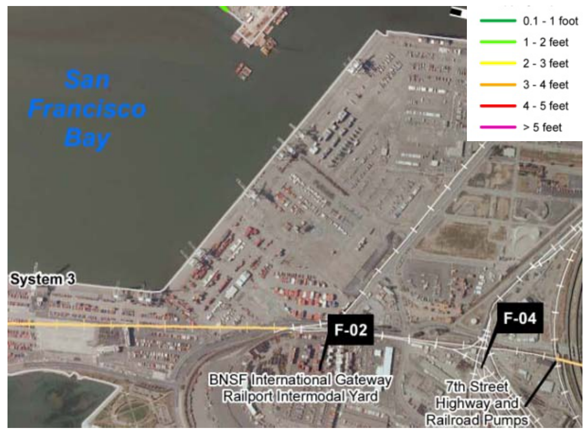


Projected Inundation with 55 inch SLR + 100-yr SWEL

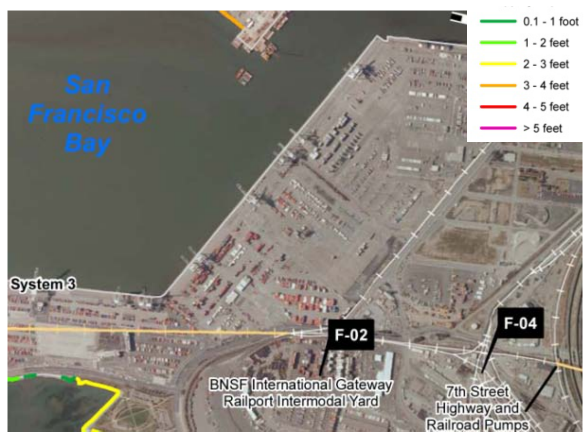
Consequence Rating (out of 5): 3.00	
Capital improvement cost	Likely to cost at least as much as a bus facility (5)
Time to rebuild	Likely at least 5 years (5)
Public safety	Not applicable (1)
Economic impact - goods movement	Crucial to goods movement (5)
Economic impact - commuter route	Not applicable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



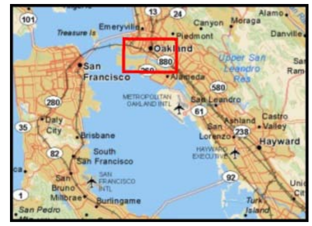
Projected Overtopping Depth at 16 inch SLR + 100-yr SWEL



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

Asset Risk Profile

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



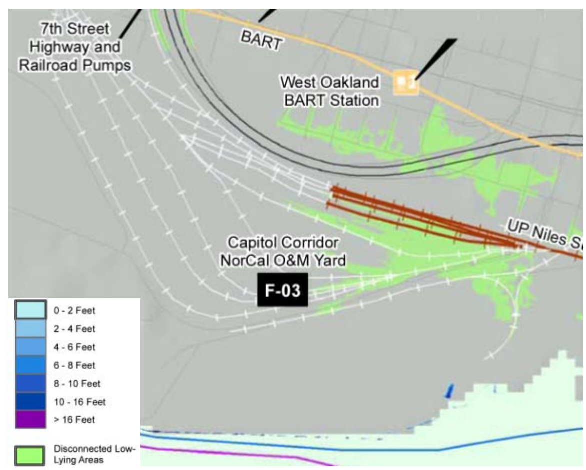
Asset Location / Jurisdiction
Oakland / Capitol Corridor JPA

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.

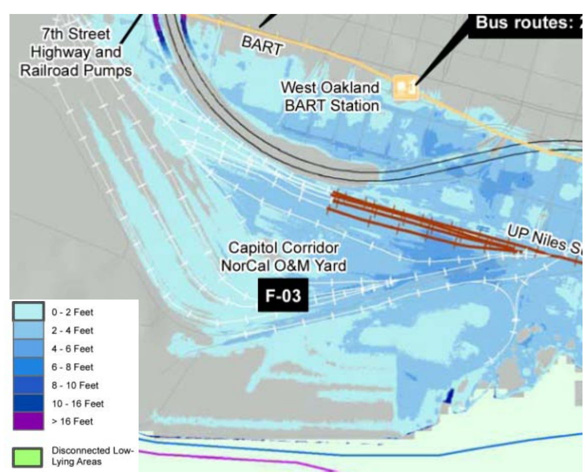
Characteristics:

- 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

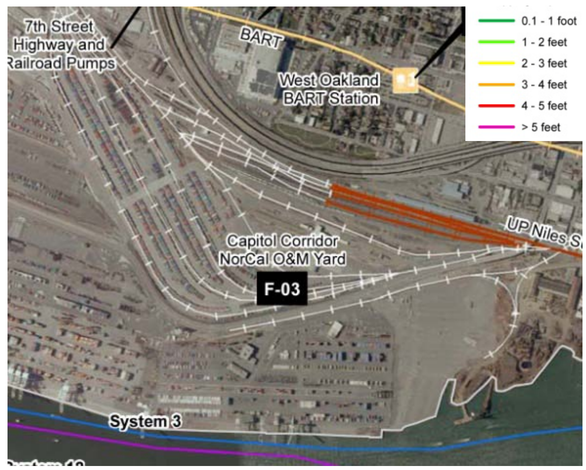


Projected Inundation with 55 inch SLR + 100-yr SWEL

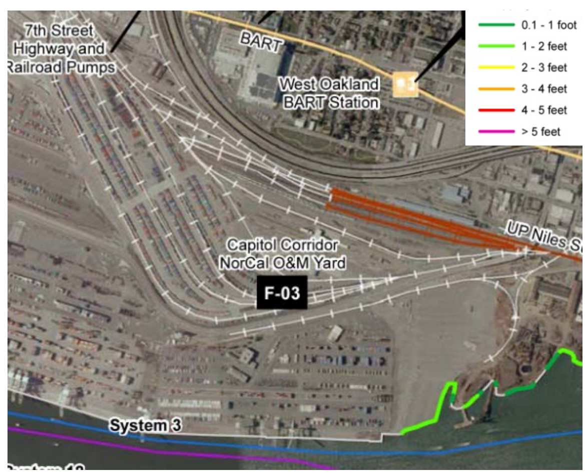
Consequence Rating (out of 5): 2.33	
Capital improvement cost	Likely at least as much as a bus facility (5)
Time to rebuild	Likely within 5 years (3)
Public safety	Minor consequence (1)
Economic impact - goods movement	Not applicable (1)
Economic impact - commuter route	Supports Capitol Corridor service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

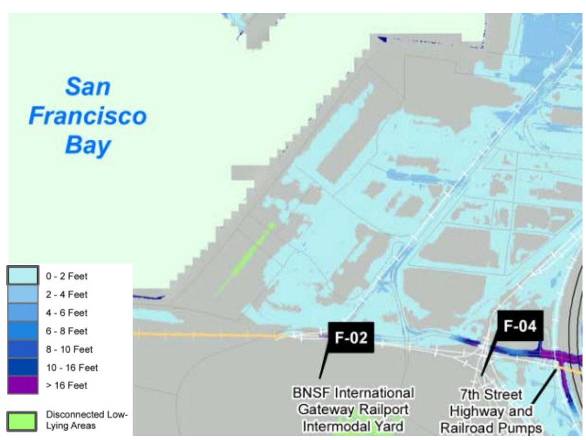
Asset Location / Jurisdiction
Oakland / Caltrans

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

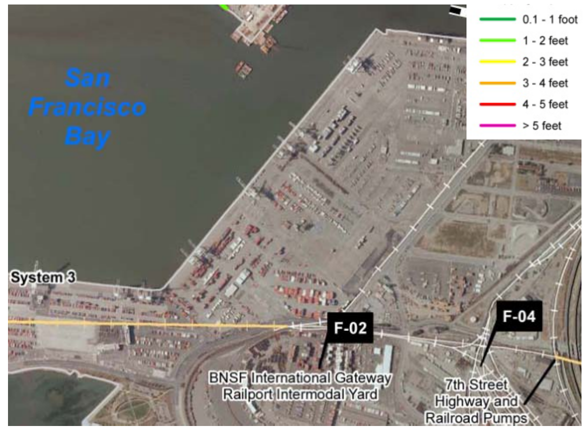


Projected Inundation with 55 inch SLR + 100-yr SWEL

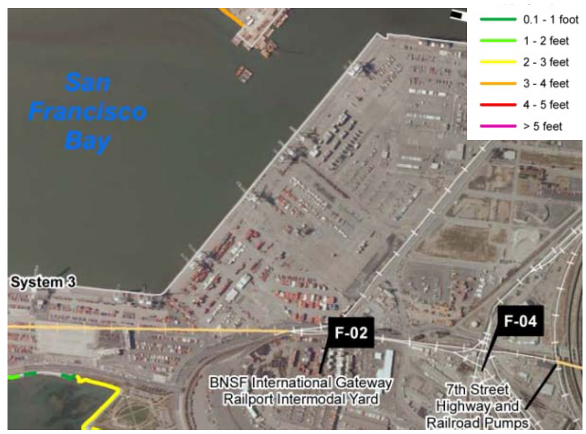
Consequence Rating (out of 5): 2.00	
Capital improvement cost	Likely less than $20 million (no structures of appreciable size) (1)
Time to rebuild	Likely within 2 years (no structures of appreciable size) (1)
Public safety	Minor consequence (1)
Economic impact - goods movement	Supports I-880 and UPRR; 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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