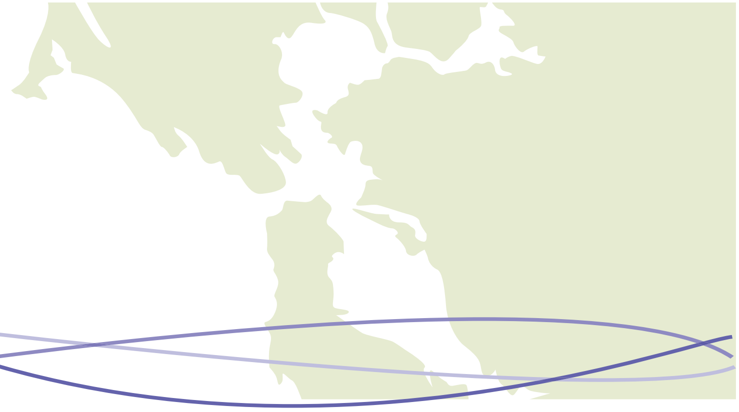
Adapting
to Rising Tides



Vulnerability & Risk Assessment Report

September, 2012

SAN FRANCISCO BAY CONSERVATION AND DEVELOPMENT COMMISSION
50 California Street, Suite 2600 San Francisco, CA 94111
Information: (415) 352-3600 Fax: (415) 352-3606
Web site: http://www.bcdc.ca.gov

Chapter 1. Introduction to the ART Vulnerability and Risk Assessment

The Adapting to Rising Tides (ART) project is a collaborative effort to evaluate how the San Francisco Bay Area can become more resilient to climate change, in particular sea level rise and storm events. This project will ultimately provide guidance on two broad questions:

> *How will climate change impacts of sea level rise and storm events affect the future of Bay Area communities, infrastructure, ecosystems and economy?*
>
> *What strategies can we pursue, both locally and regionally, to reduce and manage these risks?*

The goal of the ART project is to increase the Bay Area's preparedness and resilience to sea level rise and storm events while protecting critical ecosystem and community services.

The project study area is a portion of the Alameda County shoreline, from Emeryville to Union City, and inland areas potentially exposed to mid- and end-of-century sea level rise and storm event impacts (Figure 1). This area was selected based on local community and stakeholder interest and capacity for participation, its diverse shoreline features, and presence of regionally significant transportation infrastructure.

Figure 1. The ART project area is located in Alameda County on the eastern shoreline of San Francisco Bay.

The ART is evaluating twelve asset categories[1], including:

- Airport
- Community land use, services & facilities
- Contaminated lands
- Energy infrastructure & pipelines
- Ground transportation
- Hazardous materials
- Natural areas
- Parks & recreation areas
- Seaport
- Structural shorelines
- Stormwater
- Wastewater

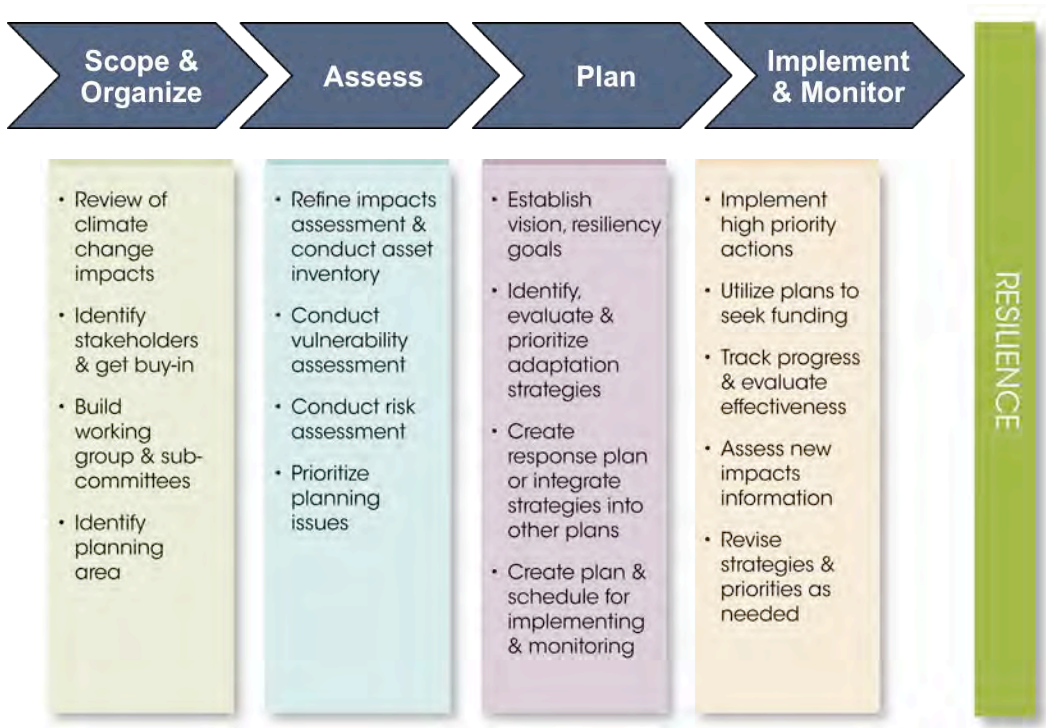
This report presents the methods, data and findings of a vulnerability and risk assessment conducted for assets in each of these twelve categories.

[1] A detailed description of each asset category is provided in the Existing Conditions and Stressors Report available along with other ART project resources at www.adaptingtorisingtides.org.

Purpose of the Assessment

The purpose of the assessment is to identify the underlying causes and components of vulnerability and risk of shoreline and community assets in the ART project area to sea level rise and storm events. Conducting a vulnerability and risk assessment is a key part of the Assess step in the project's planning process (see Figure 2). The assessment provides a foundation for the remaining two project steps in which appropriate adaptation response and implementation strategies will be considered.

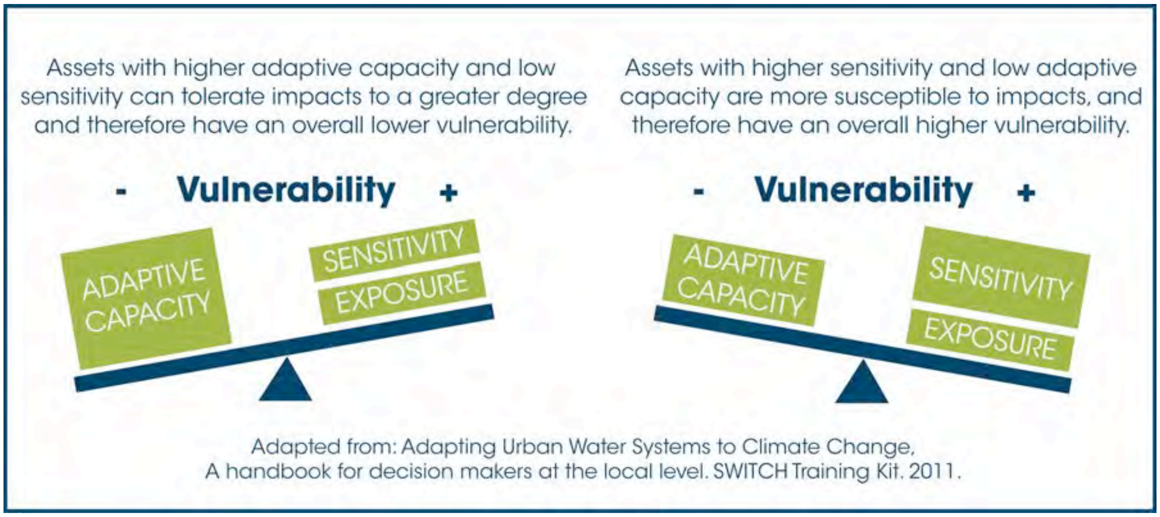
Figure 2. The ART adaptation planning process is based on a model developed by ICLEI Local Governments for Sustainability.



Key Concepts of Vulnerability and Risk

Vulnerability is the degree to which assets – services, facilities and systems – are susceptible to or unable to accommodate adverse impacts of climate change, and is defined by three primary factors: exposure, sensitivity and adaptive capacity (ICLEI 2009). In the ART project, which is focused on the climate impacts of sea level rise and storm events, **exposure** is defined as whether and to what degree a geographic area will be inundated. **Sensitivity** is the degree to which an asset is impaired by a climate impact. **Adaptive capacity** is the ability of an asset to accommodate or adjust to an impact to maintain its primary function. In general, assets with high sensitivity and low adaptive capacity are more susceptible to impacts and therefore have a higher overall vulnerability. Alternatively, assets with high adaptive capacity and low sensitivity can tolerate impacts to a greater degree, and therefore have a lower overall vulnerability (Figure 3).

Figure 3. Vulnerability is in general determined by the relationship among three components: exposure, sensitivity and adaptive capacity.



Risk is the threat posed by an adverse climate impact and is a function of two components: the magnitude of the consequences should an impact occur and the likelihood of impact occurring. Consequence was evaluated through four key assessment frames: economy, environment, governance, and society and equity. For example, there may be significant consequences to the economy if energy distribution infrastructure is disrupted, however depending on the location of the asset there may not be direct consequences on the environment. Alternatively, if a wastewater treatment plant impaired there could be consequences on the economy and the environment, as well as on society and equity and potentially governance.

To evaluate vulnerability and risk the ART project assessed both the potential for adverse effects on each asset's physical condition as well as its function. In addition, the evaluation considered individual assets as well as systems of assets within the larger shoreline community. Evaluation of both physical condition and function will enable a broader discussion of vulnerability and risk across the asset categories that is necessary to inform the development of integrated, cross-sectoral and cross-jurisdictional adaptation response strategies. It is also necessary to ensure that assets can continue to serve their current role or roles. For example, while the Port of Oakland's seaport may not be directly affected by sea level rise in the near term, the rail and roadways it relies on will be affected, which in turn will have a significant effect on goods movement, which will affect seaport operations.

Assessment Approach

The ART assessment provided an opportunity to develop, test and refine approaches and methods that could be used by others to plan for climate change adaptation. In developing the approach used in this assessment, ART project staff reviewed over 25 journal articles, regional frameworks and community-driven assessments. These assessments were evaluated for their transparency, replicability and clarity of adaptation outcomes. Based on the results of this review, and with input from working group members, both quantitative and qualitative approach was developed to evaluate the vulnerability and risk of assets in all categories. ART project staff conducted a data-driven desktop analysis and elicited best professional judgment through a survey, individual interviews, and input from working group members and other topical experts.

The qualitative and quantitative approaches of the assessment both addressed a number of guiding vulnerability and risk questions that were broad enough to be relevant to all of the asset categories, yet specific enough to inform the future consideration of adaptation strategies.

Laying the Groundwork

The ART assessment served as an opportunity to develop, test and refine adaptation planning methods and approaches that can be used by others. A number of aspects of the assessment methods and approach were explored:

Identifying overarching key questions that can inform the physical and functional vulnerability of a variety of asset types.

Integrating four, overarching frames – economy, environment, governance, and society and equity – into the evaluation of vulnerability and risk for all assets.

Standardizing the analysis of vulnerability and risk across diverse asset types.

Supplementing desktop analyses conducted by project staff and partners with expert input (best professional judgment) from local asset managers.

Guiding vulnerability questions:

- If exposed to a climate impact, would the asset be physically impaired?
- If exposed to a climate impact, would the asset be functionally impaired?
- If compromised would the asset maintain function?
- If disrupted or disabled, could the asset be restored to function quickly, easily, or in a low-cost manner?
- Is there the ability to improve the asset's capacity to cope with a climate impact quickly, easily, or in a low-cost manner?

Guiding risk question:

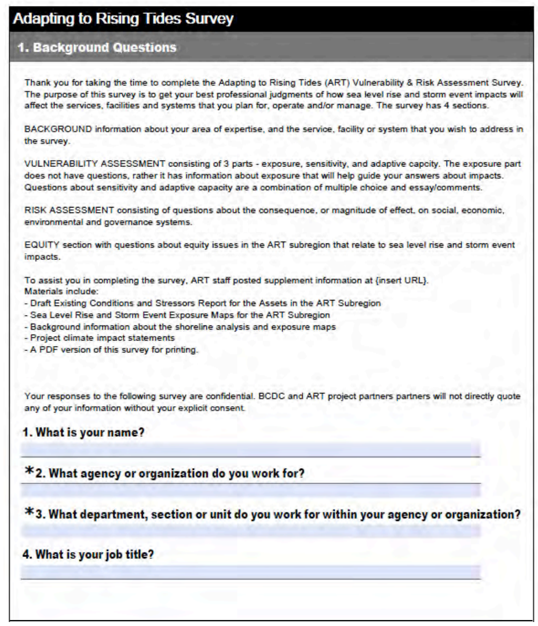
- If exposed to a climate impact, what is the expected magnitude of consequences on the economy, environment, governance, society and equity?

<u>Quantitative Data-driven Desktop Analysis</u>
Project staff, with assistance and input from working group members, project partners and consultants, conducted analyses informed by the Existing Conditions and Stressors Report completed by project staff Fall 2011, asset-specific metrics (characteristics and conditions), a

shoreline study, a socio-economic evaluation, a parks and recreation area economic analysis, and a GIS-based exposure analysis[2].

In addition, two white papers were developed in support of the ART project assessment. The first, ***Addressing Social Vulnerability and Equity in Climate Change Adaptation Planning***[3], addresses issues of social vulnerability and equity to provide a more accurate picture of the consequences of sea level rise and storm impacts, and to facilitate the development of equitable adaptation strategies. The second, ***Addressing the Role of Institutions in Climate Change Adaptation***, examines the implications of planning for climate change on governance and institutions not only in the ART project area but also for the larger Bay Area region.

Figure 4. The ART Survey was completed by over 50 asset managers and topical experts.



Adapting to Rising Tides Survey

1. Background Questions

Thank you for taking the time to complete the Adapting to Rising Tides (ART) Vulnerability & Risk Assessment Survey. The purpose of this survey is to get your best professional judgments of how sea level rise and storm event impacts will affect the services, facilities and systems that you plan for, operate and/or manage. The survey has 4 sections.

BACKGROUND information about your area of expertise, and the service, facility or system that you wish to address in the survey.

VULNERABILITY ASSESSMENT consisting of 3 parts - exposure, sensitivity, and adaptive capcity. The exposure part does not have questions, rather it has information about exposure that will help guide your answers about impacts. Questions about sensitivity and adaptive capacity are a combination of multiple choice and essay/comments.

RISK ASSESSMENT consisting of questions about the consequence, or magnitude of effect, on social, economic, environmental and governance systems.

EQUITY section with questions about equity issues in the ART subregion that relate to sea level rise and storm event impacts.

To assist you in completing the survey, ART staff posted supplement information at {insert URL}.
Materials include:
- Draft Existing Conditions and Stressors Report for the Assets in the ART Subregion
- Sea Level Rise and Storm Event Exposure Maps for the ART Subregion
- Background information about the shoreline analysis and exposure maps
- Project climate impact statements
- A PDF version of this survey for printing.

Your responses to the following survey are confidential. BCDC and ART project partners partners will not directly quote any of your information without your explicit consent.

1. What is your name?

***2. What agency or organization do you work for?**

***3. What department, section or unit do you work for within your agency or organization?**

4. What is your job title?

<u>Qualitative Vulnerability and Risk Survey</u>
To solicit best professional judgment on vulnerability and risk, a survey was developed and administered to the working group and other topical experts (Figure 4). The survey was based on a similar effort led by ICLEI Local Governments for Sustainability[4] that assessed San Diego Bay. The survey consisted of questions about the sensitivity and adaptive capacity of the particular assets operated, managed or owned by the respondent. The survey also asked for input on the potential consequences to the asset, or to the larger system or community that relies on the asset, if impacts were to occur. Lastly, the survey included a section focused on the potential for equity issues, such as disproportionate burden on vulnerable populations if an impact were to occur (see Appendix A).

Survey respondents were provided with background information including the project's climate impact statements, Existing Conditions and Stressors Report, and the sea level rise and storm event inundation maps to assist them in answering the questions. Survey respondents were asked to draw on their knowledge of the geographic area, the asset, and any past experience with flooding or storms in considering vulnerability and risk.

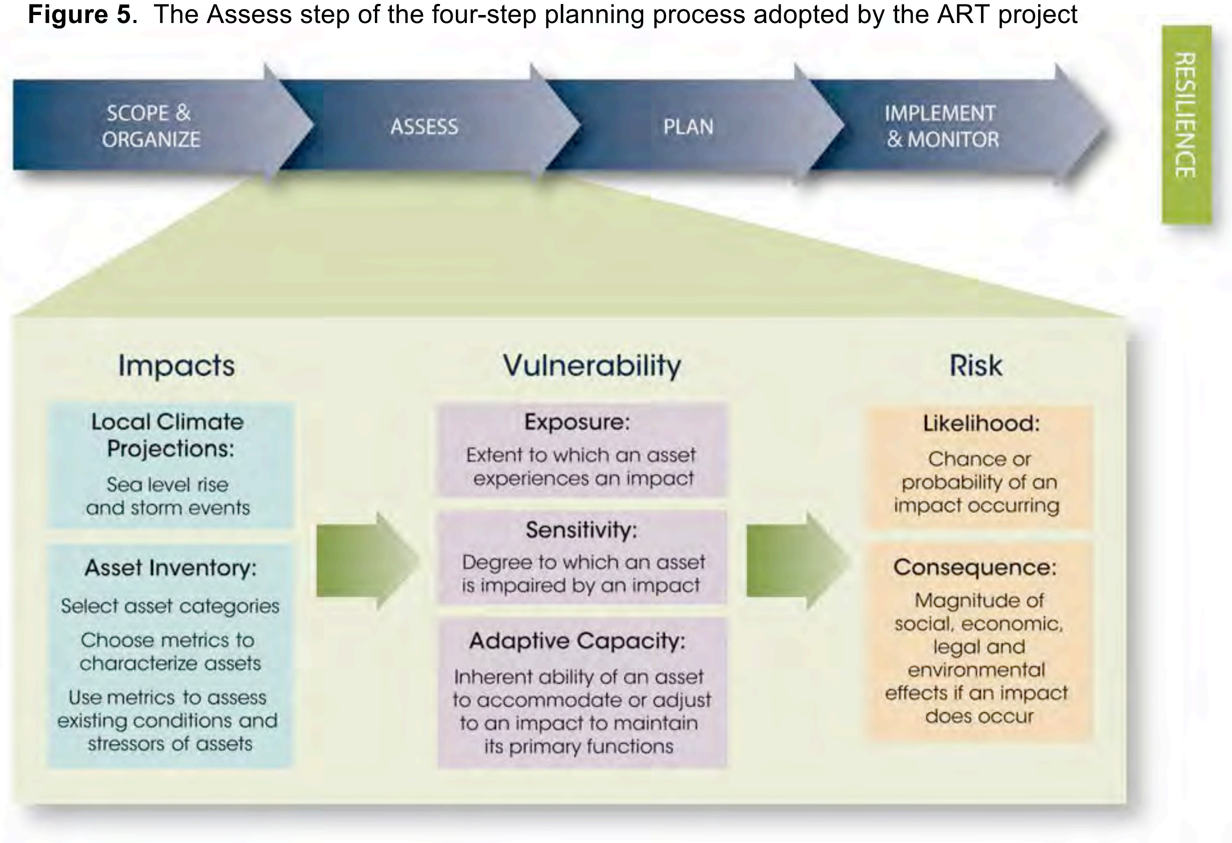
Specific Components of the Vulnerability and Risk Assessment

There are three elements of the "Assess" step of the adaptation planning process (Figure 5). The first element - Impacts - included selecting local climate projections and impacts, and identifying and describing shoreline and community assets to be evaluated. The impacts assessment completed by project staff and working group members is summarized in the project's Climate Impact Statements and Existing Conditions and Stressors Report[5].

---

[2] Detailed technical information on these analyses is provided in the appendices to this report.
[3] http://www.adaptingtorisingtides.org/equity/
[4] ICLEI SD Bay survey reference
[5] Available at www.adaptingtorisingtides.org

Figure 5. The Assess step of the four-step planning process adopted by the ART project



The remaining two elements of the Assess step, vulnerability and risk, are the subject of this report. The individual components of vulnerability and risk, and how the ART project both defined and evaluated them, are described in detail below.

Exposure

Exposure is the extent to which an asset experiences a specific climate impact. Five impacts associated with sea level rise and storm events are defined in the scope of the ART vulnerability and risk assessment:

- More frequent extreme high sea level events cause more frequent flooding in areas that are already flood-prone
- With longer duration extreme high sea level events, flooding lasts longer
- Higher high tides, shifts in tidal range, and increases in depth and duration of tidal inundation cause frequent or permanent inundation of areas that are not currently in the daily tidal range
- Higher Bay water level causes changes in wave activity in the Bay leading to increased shoreline erosion and waves over-topping shoreline protection
- Higher Bay water level leads to elevated groundwater levels and salinity

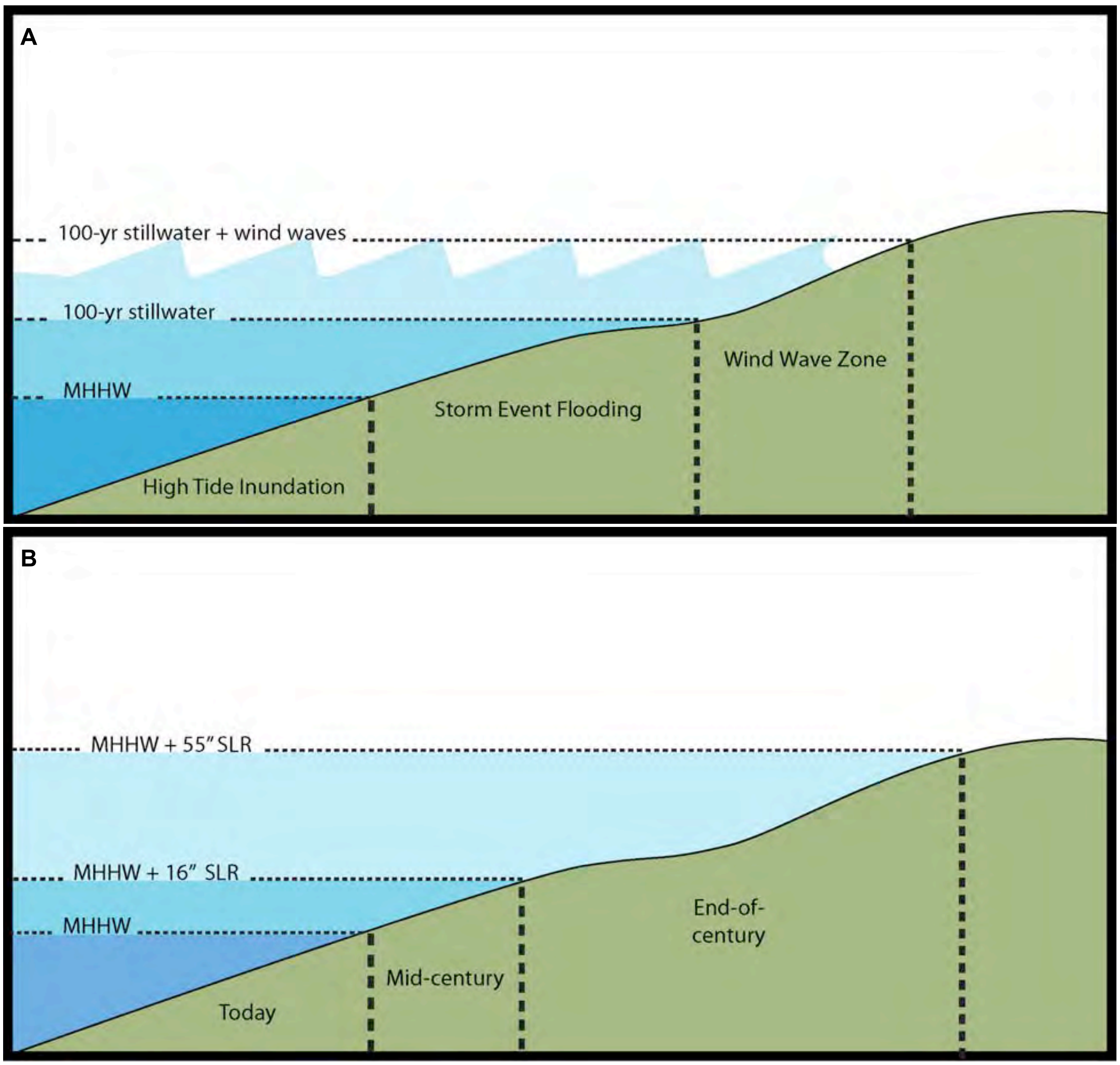
Refined sea level rise maps were developed for six future climate scenarios (AECOM 2011 and Chapter 2) in order to evaluate exposure to four of the five climate impacts[6]. The six scenarios are based on two sea level rise projections and three Bay water levels (Figure 6). The two sea level rise projections, 16 inches (40 cm) and 55 inches (140 cm), correlate approximately to mid- and end-of-century timeframes. These projections are consistent with the October 2010 State of

[6] Changes in groundwater levels due to sea level rise were not evaluated.

California Sea Level Rise Interim Guidance[7] and are within the range of projections recently reported by a National Academy of Science study of sea level rise on the west coast (NRC 2012). The NRC study found that the potential range of projected sea level rise values is fairly wide. For the Bay Area, the range of values is 4.7 to 24 inches (12 to 61 cm) at mid-century and 16.5 to 65.7 inches (42-167 cm) at end-of-century.

The Bay water levels selected correspond to three tide and storm conditions: the highest average daily high tide represented by mean higher high water (MHHW), hereafter "high tide" or "daily high tide"; the 100-year extreme water level, also known as the 100-year stillwater elevation (100-year SWEL), hereafter "100-year storm" or "storm event"; and the 100-year extreme water level coupled with wind-driven waves, hereafter "storm event with wind waves", or "wind waves."

Figure 6. Conceptual diagram of the three Bay water levels evaluated in the ART project (A) and the increase in the extent and depth of high tide inundation from 16 inches of sea level rise (B).



[7] CO-CAT 2010

The daily high tide was selected to inform which shoreline areas not currently exposed to tidal action could be exposed to the high tide with sea level rise. This scenario is important because exposure to the daily high tide would result in frequent or permanent inundation, potentially leading to the slow yet chronic degradation of an asset's physical condition or function.

In contrast, shoreline areas exposed to a 100-year storm event with sea level rise could be subjected to infrequent and temporary, but potentially severe, inundation. Extreme storms can cause overtopping and erosion of shoreline protection assets, exposing large inland areas to fairly deep flood depths and high velocity flows. Wind waves can elevate water levels significantly above stillwater levels, potentially increasing the severity of flooding. It is critical, therefore, to consider the effect wind driven waves could have on inland inundation during a coastal storm event.

During a storm event with wind waves the inland extent of flooding could be greater (than the area exposed to storm event inundation), and the depth of flooding in areas already exposed could be deeper. Because waves both propagate and dissipate as they move over land, it was not possible to estimate the additional depth of inundation due to wind waves in areas already exposed to storm event flooding, nor was it possible to determine the depth of inundation in areas exposed to wind waves only. Therefore, the storm event with wind wave scenario results were interpreted as (1) all assets exposed to storm event flooding could also be exposed to potentially deeper inundation due to wind waves, and (2) assets exposed to wind waves only could potentially be inundated with shallow depths for short durations.

While these water levels were selected because they represent a reasonable range of Bay conditions that will affect flooding and inundation along the shoreline, other tide/storm scenarios could also be informative. For example, the "King Tide" is an extreme high tide, higher than MHHW, which occurs annually when the sun and moon's gravitational forces reinforce each other[8], while a 10 or 25-year return period storm occurs more frequently, and is less sever then, a 100-year storm. The tide and storm condition used in an exposure analysis should be selected during the "Scope and Organize" phase of an adaptation planning project, and will depend on the type of shoreline assets under investigation, and the type of scenarios that are most useful to developing adaptation strategies.

Coastal Storm Events

Source: Mark Taylor, EBRPD

In California, coastal storms generally occur in the winter. Low air pressure during a storm increases wind activity, which in turn generates wind-driven waves (Bromirski and Flick 2008). The strength and frequency of coastal storms is influenced by climate patterns such as the El Niño Southern Oscillation, which generally results in persistent low air pressure, high winds, and increased rainfall (Cayan et al. 2008).

Storm activity is not projected to intensify or appreciably change this century, making sea level rise the dominant factor controlling increased shoreline flooding and erosion. Rising sea levels will not only increase tide levels, causing flooding of inland areas, but will allow erosive wave energy to reach farther inland.

With sea level rise, by the end of the century flooding caused by today's 100-year storm event is projected to occur annually along the California coast (Bromirski et al. 2012).

[8] For information about King Tides visit californiakingtides.org/

Sensitivity

Sensitivity is the degree to which an asset is impaired by a climate impact. Metrics used to guide the analysis of sensitivity for both built and natural assets include:

- Type of land use or service provided, e.g., residential land uses, facilities that are critical for emergency response, or provide key community services to at-risk or vulnerable, less mobile populations
- Susceptibility of structures due to design or function, e.g., foundation type, flood-proofing, below-ground entrances or uses
- Historic effects of flooding, e.g., loss of function, disruption or delay of service
- Current depth to groundwater
- Seismic susceptibility due to increased liquefaction potential
- Presence of contaminated soil or groundwater
- Elevation relative to current Bay water level, e.g., low, mid, or high marsh habitat
- Capacity to keep up with sea level rise, e.g., vertical accretion and subsidence rates
- Capacity for horizontal (inland) migration, lateral accommodation space available
- Species value - biodiversity, unique, sensitive, state or federally listed species
- Habitat value - wildlife corridor, high tide refugia, part of landscape mosaic

Adaptive Capacity

Adaptive Capacity is the ability of an asset to accommodate or adjust to an impact and thus to maintain its primary functions. Metrics used to guide the analysis of adaptive capacity for both built and natural assets include:

- Potential for partially compromised asset to maintain key functions and continue to provide necessary community services
- Asset redundancy, e.g., alternative comparable asset available
- Capacity of the system to function without an asset or if an asset is compromised
- Ability to restore asset function quickly, easily, or in a low-cost manner if compromised
- Disaster or emergency response resources, e.g., onsite staff, backup power, equipment for cleanup, temporary flood protection, pumps, "friends of" organizations or volunteers
- Operation and maintenance costs
- Capital improvement costs
- Potential for reengineering or redesign
- Status of existing plans, e.g., emergency or disaster response plan, master plans, etc
- Complexity of regulations governing operations, maintenance or capital improvements
- Complexity of decision-making regarding operations, maintenance or capital improvement planning and implementation

Consequences

The expected magnitude of the economic, environmental, governance, societal and equity consequences if an impact were to occur was evaluated in a qualitative manner for all assets. The consequences of an impact on the primary function of an asset and on the system of assets (if one exists) were considered in evaluating magnitude. For example, the loss of an essential sewage pumping station could be significant not only to the managing agency or organization, but to the greater community or system as well. The magnitude and type of consequences are important when identifying and prioritizing adaptation response strategies.

A number of general considerations were developed to guide the assessment of consequences including:

- The potential scale of impact, e.g., the population size, land area, and resources that would be affected.
- The potential severity of impact, e.g., total physical loss or complete disruption of function versus frequent minor damage that could be repaired.
- Cumulative costs/harm due to frequent but relatively minor events
- Cumulative costs/harm due to infrequent but extreme events

Specific considerations were developed to help frame the approach to each of the guiding risk questions.

Guiding Risk Questions	Specific considerations
What is the expected magnitude of consequences on the economy?	• Is there a disruption to the goods movement network? • Is there a disruption to job / employment centers? • What are the costs associated with repair, replacement and reopening of the asset?
What is the expected magnitude of consequences on the environment?	• Will there be an impact or disruption to ecosystem services such as flood protection? • Will populations of threatened or endangered species be impaired? • Does the asset serve as an important ecological corridor or serve as an important link in a large habitat network
What is the expected magnitude of consequences on governance?	• Will there be an impact on land use, facility, or public planning processes? • Will the impact require inter-agency coordination beyond existing agreements (if they exist)? Will the impact make existing agreements inadequate or inappropriate? • Will the impact result in an unclear legal or regulatory situation (e.g., unclear legal responsibilities, authorities, or compliance/enforcement dilemmas)?
What is the expected magnitude of consequences on society and equity?	• Is there a potential for public health and safety related impacts? • Is there a loss of recreational opportunities/shoreline access? • Does the asset serve an underserved community? • Does the asset serve individuals/communities with limited mobility such as elderly, disabled or transit dependent populations?

In addition to the qualitative assessment of consequences conducted for all of the asset categories, a quantitative assessment of the potential economic consequences to park and recreation areas was evaluated using a benefits transfer model with assistance from the Eastern Research Group (ERG)[9].

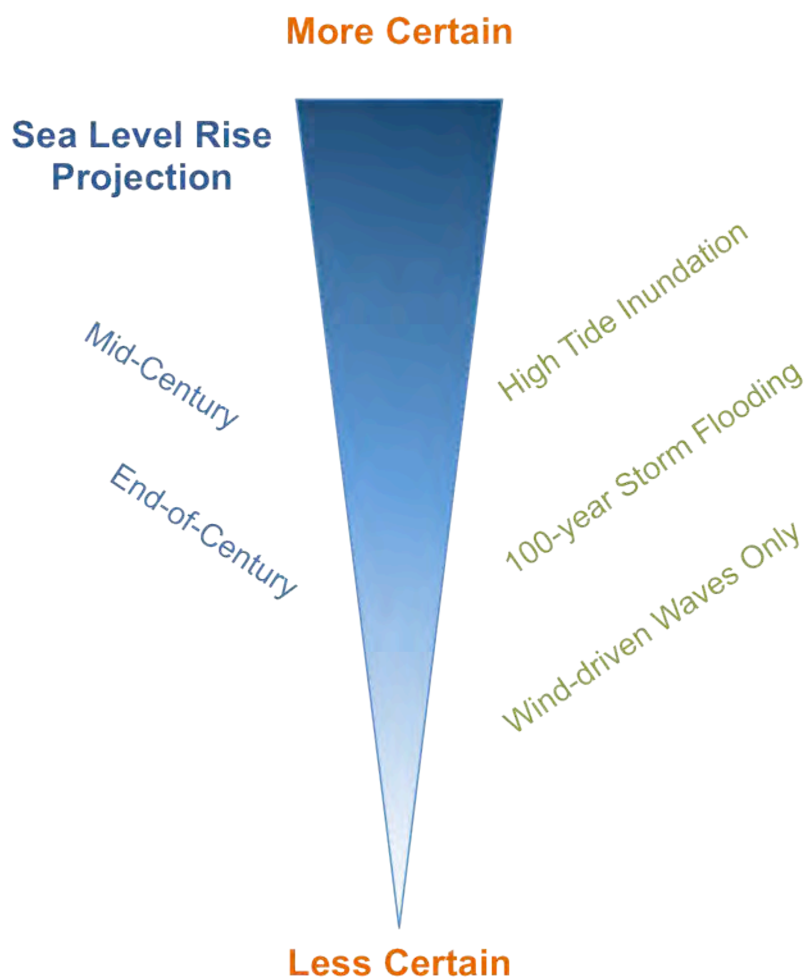
[9] *Economic Analysis of Recreational and Other Values of Parks in the Adapting to Rising Tides Project Area* prepared by the Eastern Research Group for the Adapting to Rising Tides project.

Likelihood

The likelihood of a climate impact is based on the certainty, or confidence, that the sea level rise projection and Bay water level evaluated will occur. Among the six future climate scenarios selected for the ART project, there is a greater certainty of the impacts occurring at mid-century (i.e. 16 inches of sea level rise by 2050) then at the end-of-century (i.e., 55 inches of sea level rise by 2100). There is also greater certainty that high tide inundation will occur then will flooding due to an extreme storm event (Figure 7). In addition, due to the dynamic nature of wind wave processes, there is less certainty in the potential impacts that could be caused by wind-driven waves during a storm event than for high tide or a storm event without wind wave impacts.

Likelihood can also be understood as the potential that an asset will be exposed if the climate impact does occur. For the ART project, this component of likelihood was informed by an analysis of shoreline overtopping potential. This analysis is a high-level screening tool that helps identify areas of the shoreline that are not of adequate height to prevent inland inundation if the future climate scenarios occur. This analysis, described in Chapter 2, was conducted for the ART project area in general as well as for specific representative shoreline areas (see Chapter 6, Structural Shorelines).

Figure 7. There is more certainty, and therefore a greater likelihood, in the mid-century climate change predictions then in the end-of-century predictions, and for Bay water level conditions that are more frequent such as high tide verses an extreme storm event tide.



Organization of the ART Vulnerability and Risk Assessment Report

This report presents the data, methods, and results of the vulnerability and risk assessment conducted for shoreline and community assets in the ART project area. Project staff and working group members will use the findings of this assessment to consider adaptation response strategies and implementation options.

In *Chapter 2. Sea Level Rise Mapping and Shoreline Potential Overtopping Analysis* the evaluation of exposure is described, and the inundation maps and shoreline analysis results are presented. *Chapter 3. Cross-Cutting Issues* provides an overview of the vulnerability and risk assessment findings, and highlights the cross-sectoral, cross-jurisdictional issues that will be key in considering integrated and multi-beneficial adaptation response strategies.

Chapter 4. Vulnerability and Risk Classification sets the stage for the consideration of adaptation response strategies and implementation options. Vulnerabilities and risks identified in the assessment have been classified according to characteristics that will help project participants (1) prioritize management issues, (2) guide them towards evaluating adaptation strategies, and (3) highlight where better or new coordination is needed. This chapter describes the classification approach developed by the ART project and presents the results of this last step in the Assess part of the adaptation planning process.

The vulnerability and risk of individual assets or systems of assets are detailed in the following twelve asset category chapters. For each category a summary of the exposure, physical and functional sensitivity and adaptive capacity is provided. Additionally, the potential consequences of the climate impacts on the assets are discussed through the four assessment frames (economic, environmental, governance, society and equity). At the end of each chapter, key findings are provided that summarize the asset-specific vulnerabilities and risks.

References

Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project. November 2011. Prepared by AECOM and Arcadis for the San Francisco Bay Conservation and Development Commission, Metropolitan Transportation Commission and the California Department of Transportation. Available at http://www.mtc.ca.gov/news/current_topics/10-11/sea_level_rise.htm.

Bromirski, P. D., D. R. Cayan, N. Graham, R. E. Flick, and M. Tyree (Scripps Institution of Oceanography). 2012. Coastal Flooding Potential Projections: 2000-2100. California Energy Commission. CEC-500-2012-011.

Bromirski, P.D. and R.E. Flick. 2008. Storm surge in the San Francisco Bay/Delta and nearby coastal locations. Shore & Beach. 76(3): 29-37.

Cayan, D.R., P.D. Bromirski, K. Hayhoe, M. Tyree, M.D. Dettinger, and R.E. Flick. 2008. Climate Change Projections of Sea Level Extremes Along the California Coast. Climatic Change. 87 Suppl 1): S57-S73. Doi: 10.1007/s10584-007

National Research Council. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. 2012. Prepared by the Committee on Sea Level Rise in California, Oregon, and Washington; Board on Earth Sciences and Resources; Ocean Studies Board; Division on Earth and Life Studies; National Research Council. Available from the National Academies Press at www.nap.edu/catalog.php?record_id=13389

Chapter 2. Sea Level Rise Mapping and Shoreline Potential Overtopping Analysis

To support the ART vulnerability and risk assessment a coastal engineering team conducted an analysis and developed maps to illustrate the potential extent and depth of inland inundation, and the potential location and depth of shoreline overtopping for the six future climate scenarios considered (AECOM 2011). The analysis and resulting maps are based on modeling of Bay hydrodynamics and shoreline topography. Models are simplifications of complex processes, and are therefore inherently limited in how well they can accurately represent real-world conditions (TNC and NOAA, 2011). Models can, however, provide a framework for understanding possible future conditions, and are therefore useful and necessary for decision-making undertaken in climate adaptation planning.

The analysis conducted for the ART project is based on model outputs that do not account for complex and dynamic Bay processes, future conditions such as erosion or subsidence, or the improvement or construction of shoreline protection. The resulting maps are therefore appropriate for higher-level planning studies such as the ART project, but are not intended to represent or replace detailed studies that may ultimately be necessary to address sea level rise at a local or site-specific scale.

> The ART sea level rise maps are a refinement of previous efforts completed for San Francisco Bay* because the analyses:
>
> - Used recently collected, high resolution topographic data
> - Considered wind waves
> - Determined the depth and extent of potential inundation
> - Identified hydraulically disconnected areas
>
> ** Maps based on data developed by the USGS at http://cal-adapt.org/sealevel/*

Sea Level Rise Inundation Mapping

Sea level rise inundation maps are generally constructed using a four-step process (NOAA CSC 2009). The four steps are:

Obtain and Prepare elevation data that will serve as the mapping base layer

Prepare Water Levels based on model outputs or a single value

Map Inundation using elevation data and water levels

Visualize Results using simple maps, online GIS, or interactive viewers

The data and methods used to complete each of these steps for the ART project are summarized below. See Appendix B for a detailed description of the analytical methods used.

<u>Obtain and Prepare Elevation Data</u>

Elevation data was obtained from the California Coastal Mapping Project[1], a state-federal-industry partnership. As a project partner, the U.S. Geological Survey (USGS) collected Light Detecting and Ranging (LIDAR) data for the southern portion of San Francisco Bay in 2010. This LIDAR data provided complete coverage of the ART project area up to the 16-foot (5-meter) elevation contour and had a vertical accuracy of +/- 2.8 inches (0.07 m), which exceeds USGS Guidelines and Base Specifications.

The bare-earth LIDAR[2] from the 2010 USGS collection was used to create a 2-meter horizontal grid resolution Digital Elevation Model (DEM) that served as the base layer for the ART project inundation mapping. The DEM was of sufficient resolution and detail to capture the shoreline

[1] www.opc.ca.gov/2012/03/coastal-mapping-lidar-data-available

[2] The bare-earth LIDAR had all building, structures and vegetation removed during processing

levees and flood protection assets in the project area with the exception of floodwalls, which are generally narrower than the DEM's 2-meter horizontal resolution.

Prepare Water Levels

Water level data was obtained from existing and readily available model outputs from two large-scale San Francisco Bay efforts: (1) TRIM2D modeling completed by the USGS for the Computational Assessments of Scenarios of Change for the Delta Ecosystem Project, (CASCaDE) and (2) MIKE21 modeling completed by DHI for the Federal Emergency Management Agency (FEMA) San Francisco Bay coastal hazard analysis and mapping.

The TRIM2D and MIKE21 modeled water levels provided two independent estimates of tide levels along the Alameda County shoreline. These two estimates are not directly comparable, however because the time periods of records used were different (a 100-year projection vs. a 30-year hindcast), and because only one of the models (MIKE21) accounted for wind effects. Development of water levels for the project's storm and wind wave scenarios took advantage of these differences by combining the results of the two modeling efforts. In particular, the MIKE21 model was used to account for wind setup, wave setup and 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 level.

Current water levels for mean higher high water (daily high tide), 100-year extreme water level (100-year storm), and 100-year extreme water level with wind-driven waves (100-year storm with wind waves) were determined for specific model output points within the project area. These water levels were then projected to future conditions by adding either 16 or 55 inches of sea level rise. The resulting water levels were then interpolated and extrapolated to create water surface maps for each of the six future climate scenarios.

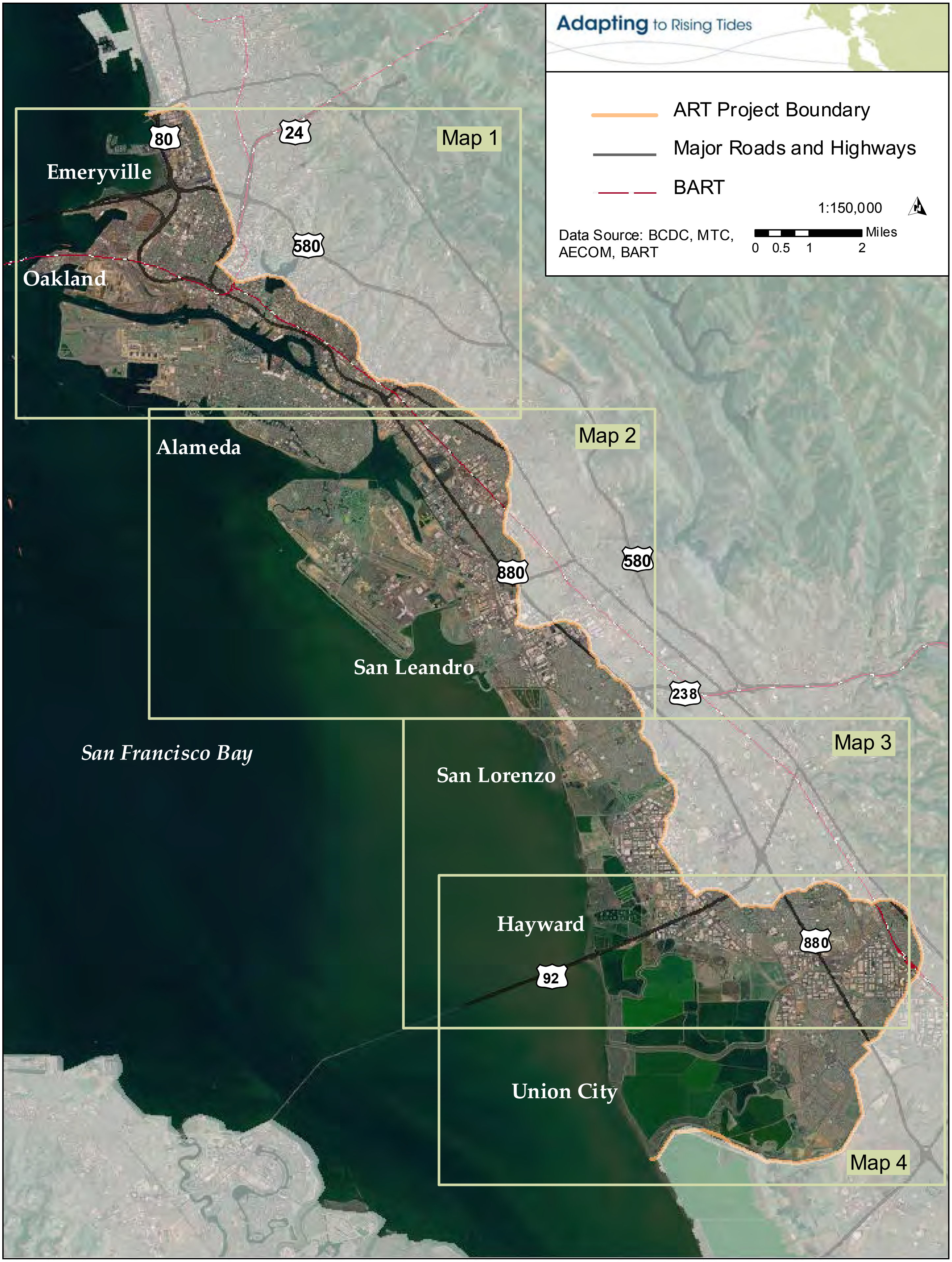
Inundation Mapping

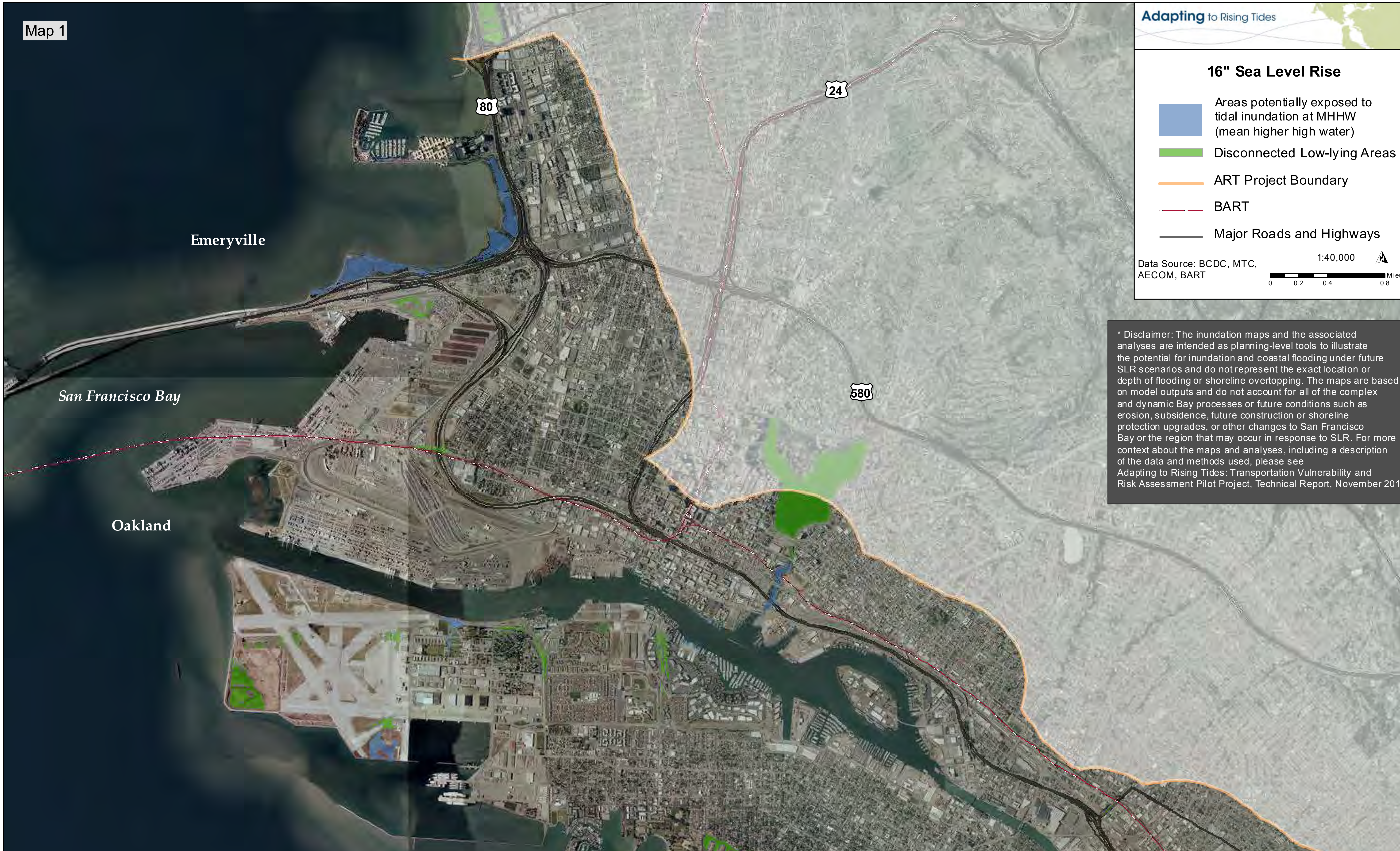
Inundation maps for six future climate scenarios were developed from the 2-meter horizontal grid resolution Digital Elevation Model (DEM) and water surface maps described above using mapping methods developed by the National Oceanic and Atmospheric Administration Coastal Services Center (Marcy et al. 2011). The methods include an assessment of hydraulic connectivity that identifies low-lying areas that are not connected to adjacent inundated areas because they are protected by levees or other topographic features, and therefore would not be flooded. These areas were uniquely identified on the final maps created for the ART project because while they are not directly exposed to sea level rise or storm event impacts, they are at risk of flooding if the topographic feature protecting them fails or breaches.

Visualize Results

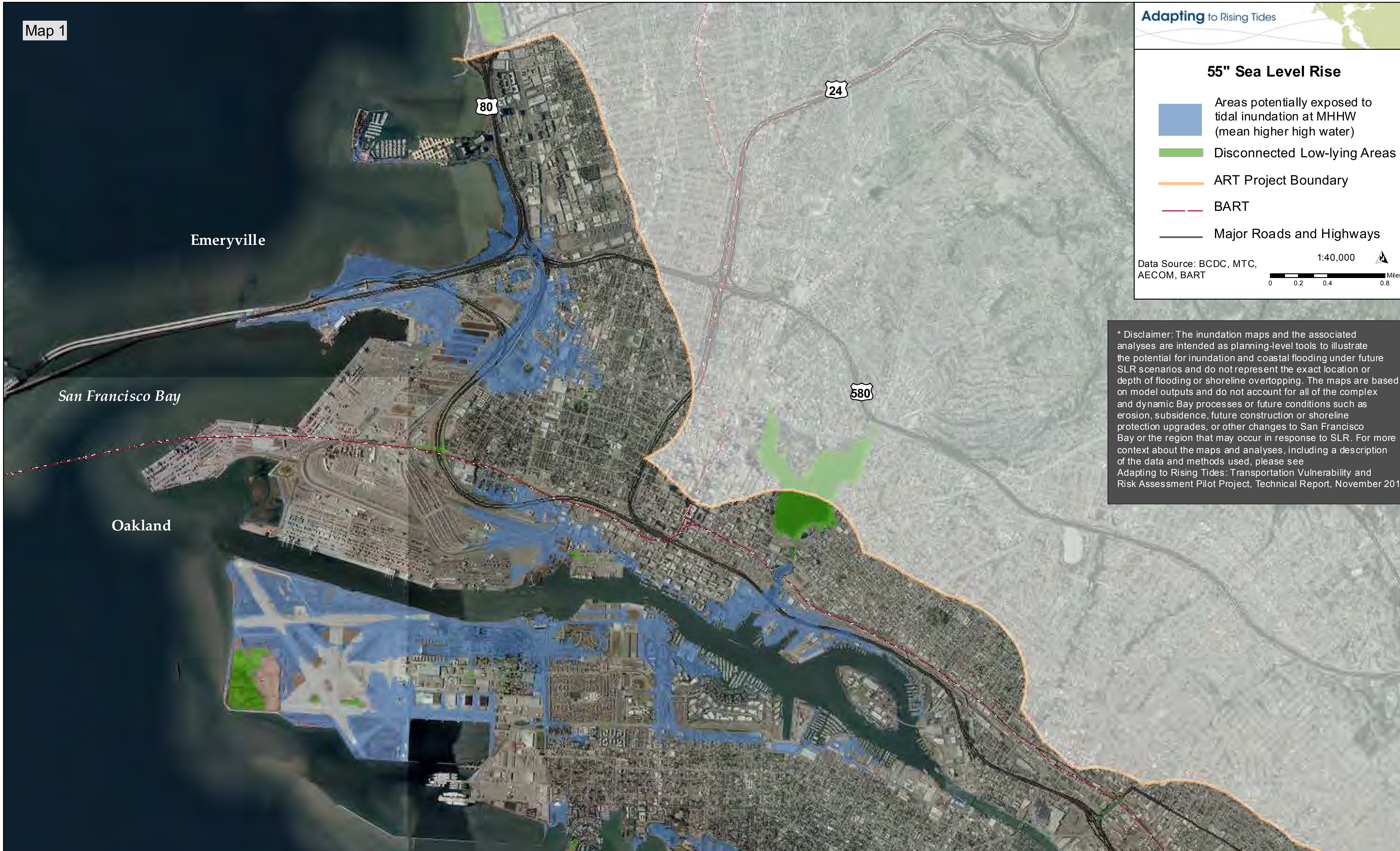
Maps visualizing the inundation analysis were developed for all six future climate scenarios. The extent and depth of inundation is depicted for the two sea level rise projections (16 and 55 inches) and for two Bay water levels - the daily high tide and the 100-year storm. Because overland wave propagation and dissipation which could significantly affect inundation depth were not evaluated, only the extent of inundation was depicted for the 100-year storm with wind waves. Based on the uncertainty of the topographic data and the modeling results, inundation depths are presented in 1-foot increments, and depths of less than 0.5 foot were not considered. Lastly, areas determined by the hydraulic connectivity analysis to be "disconnected low-lying areas "were uniquely identified on the final maps.

Sea Level Rise Maps


Adapting to Rising Tides
ART Project Boundary
Major Roads and Highways
BART
1:150,000
Miles
0 0.5 1 2
Data Source: BCDC, MTC, AECOM, BART
Map 1
Map 2
Map 3
Map 4
Emeryville
Oakland
Alameda
San Leandro
San Lorenzo
Hayward
Union City
San Francisco Bay
80
24
580
880
238
92


Map 1
Adapting to Rising Tides
16" Sea Level Rise
Areas potentially exposed to tidal inundation at MHHW (mean higher high water)
Disconnected Low-lying Areas
ART Project Boundary
BART
Major Roads and Highways
Data Source: BCDC, MTC, AECOM, BART
1:40,000
0 0.2 0.4 0.8 Miles
* 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 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.
Emeryville
San Francisco Bay
Oakland
80
24
580


Map 1
Adapting to Rising Tides
16" Sea Level Rise
Areas potentially exposed to storm event flooding (100-year stillwater)
Areas potentially exposed to wind waves during a storm event
Disconnected Low-lying Areas
ART Project Boundary
BART
Major Roads and Highways
Data Source: BCDC, MTC, AECOM, BART
1:40,000
Miles
0
0.2
0.4
0.8
* 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 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.
Emeryville
San Francisco Bay
Oakland
80
24
580


Map 1
Adapting to Rising Tides
55" Sea Level Rise
Areas potentially exposed to tidal inundation at MHHW (mean higher high water)
Disconnected Low-lying Areas
ART Project Boundary
BART
Major Roads and Highways
Data Source: BCDC, MTC, AECOM, BART
1:40,000
0 0.2 0.4 0.8 Miles
* 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 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.
Emeryville
San Francisco Bay
Oakland
80
24
580

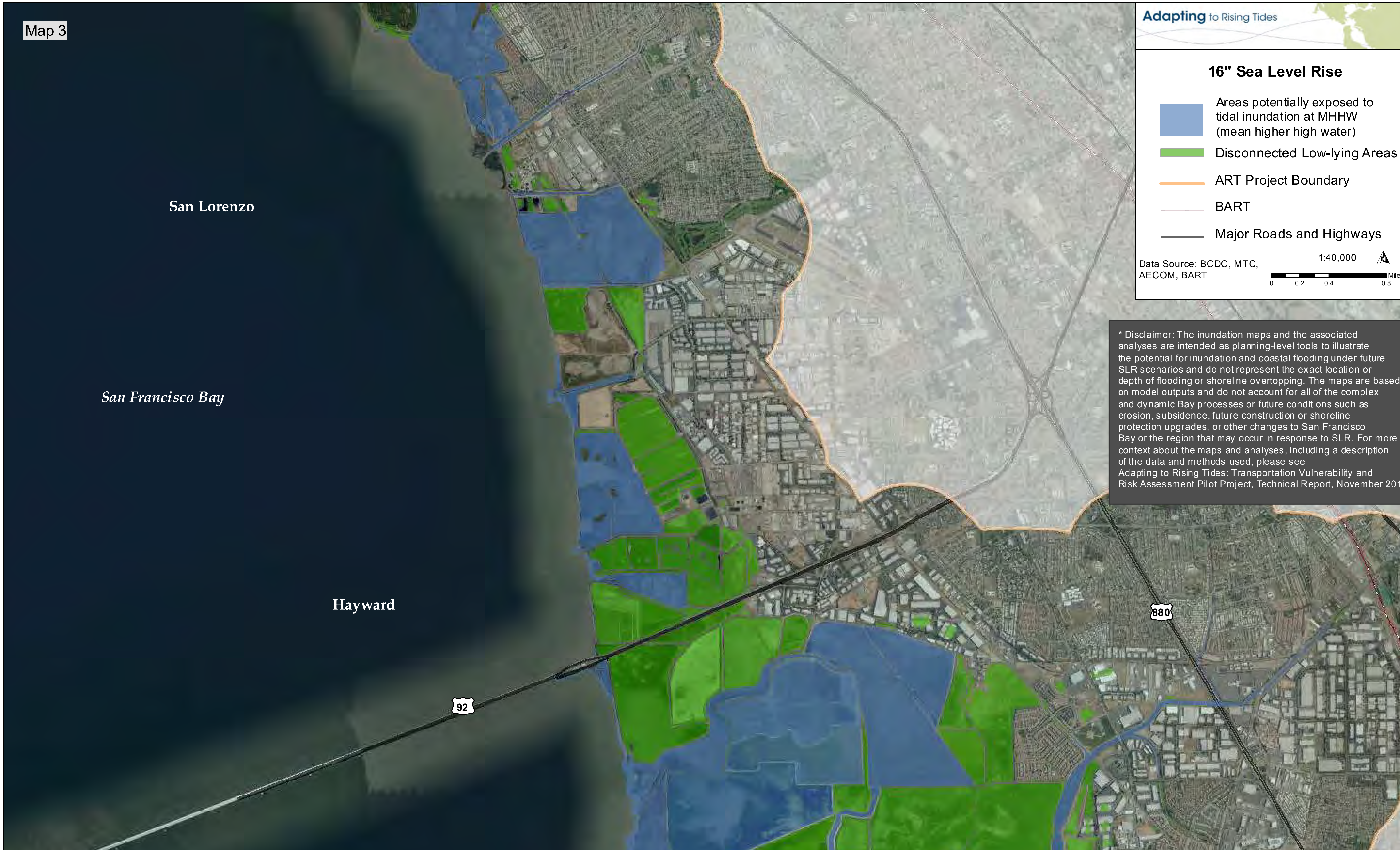

Map 1
Adapting to Rising Tides
55" Sea Level Rise
Areas potentially exposed to storm event flooding (100-year stillwater)
Areas potentially exposed to wind waves during a storm event
Disconnected Low-lying Areas
ART Project Boundary
BART
Major Roads and Highways
Data Source: BCDC, MTC, AECOM, BART
1:40,000
0 0.2 0.4 0.8 Miles
* 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 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.
80
24
580
Emeryville
San Francisco Bay
Oakland

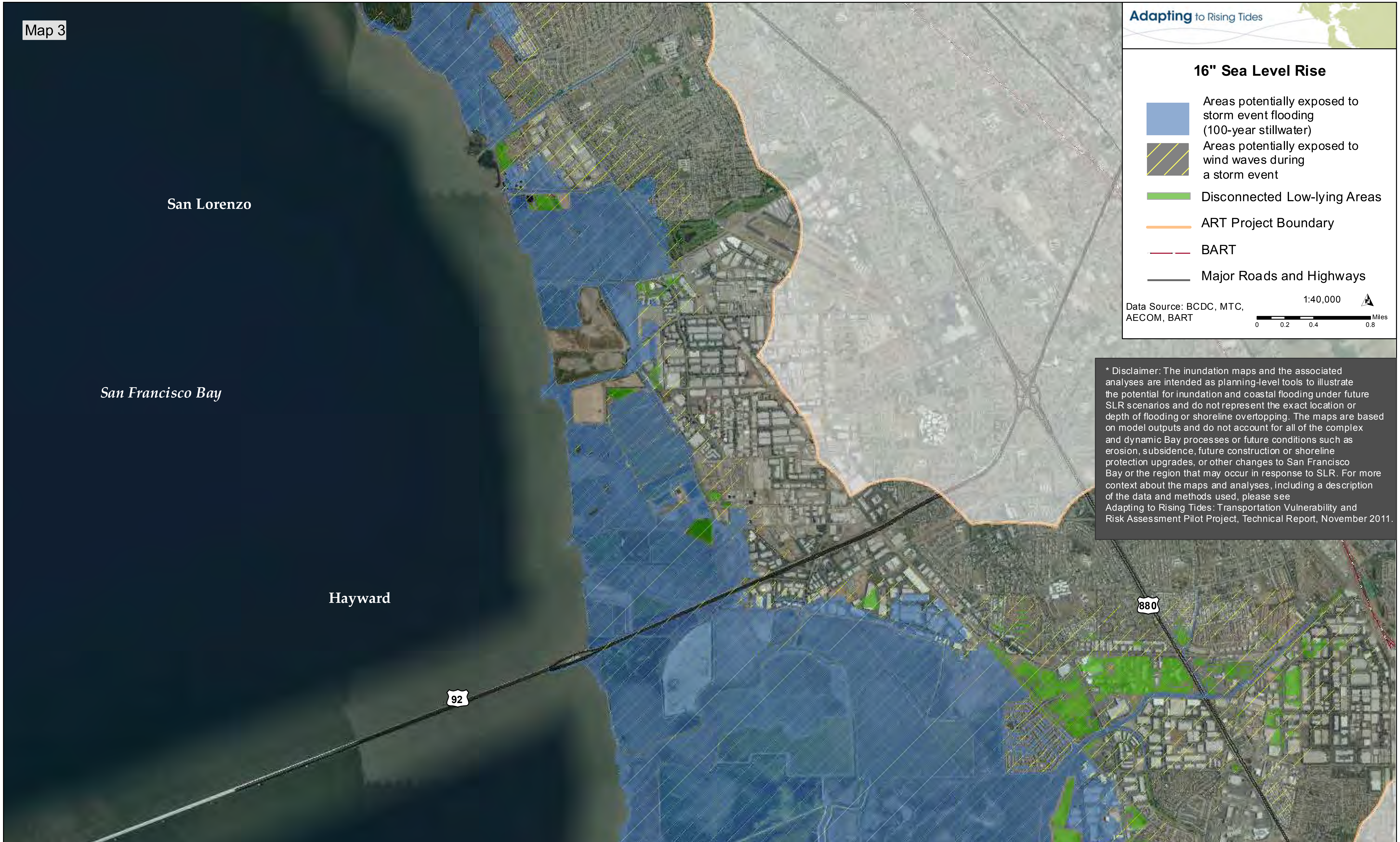

Map 2
Alameda
San Francisco Bay
San Leandro
880
Adapting to Rising Tides
16" Sea Level Rise
Areas potentially exposed to tidal inundation at MHHW (mean higher high water)
Disconnected Low-lying Areas
ART Project Boundary
BART
Major Roads and Highways
Data Source: BCDC, MTC, AECOM, BART
1:40,000
0 0.2 0.4 0.8 Miles
* 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 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.

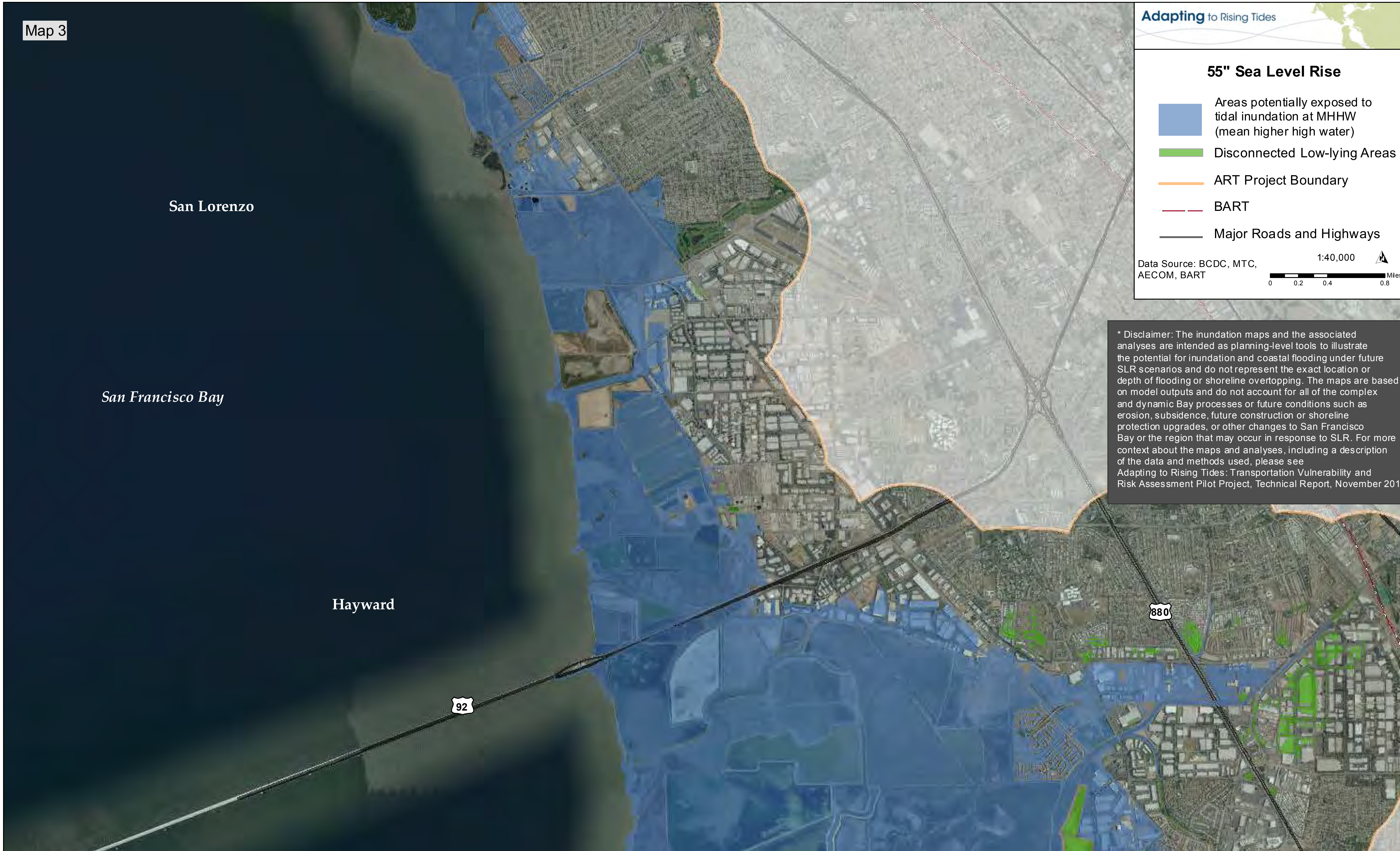

Map 2
Alameda
San Francisco Bay
San Leandro
880
Adapting to Rising Tides
16" Sea Level Rise
Areas potentially exposed to storm event flooding (100-year stillwater)
Areas potentially exposed to wind waves during a storm event
Disconnected Low-lying Areas
ART Project Boundary
BART
Major Roads and Highways
Data Source: BCDC, MTC, AECOM, BART
1:40,000
0 0.2 0.4 0.8 Miles
* 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 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.

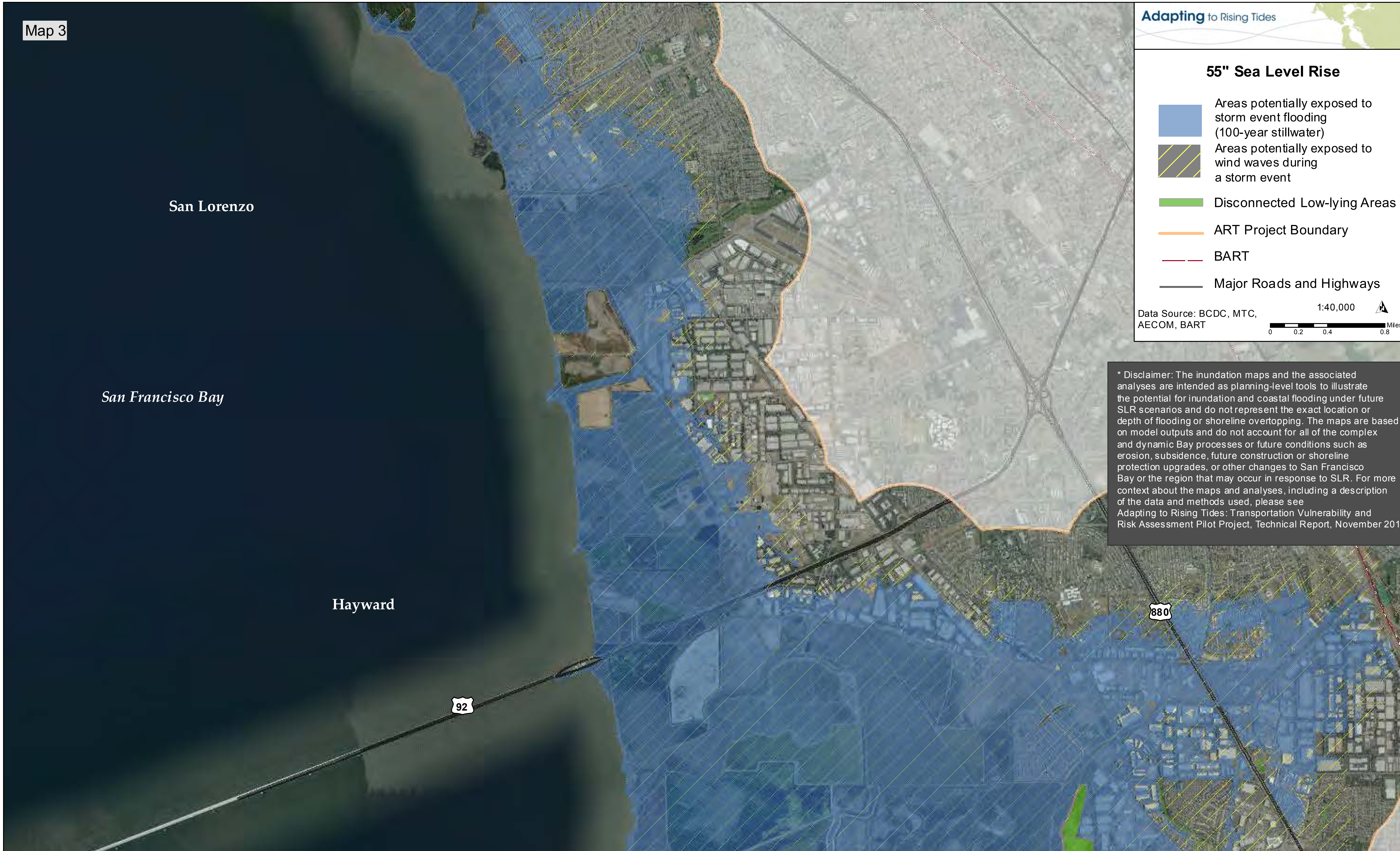

Map 2
Adapting to Rising Tides
55" Sea Level Rise
Areas potentially exposed to tidal inundation at MHHW (mean higher high water)
Disconnected Low-lying Areas
ART Project Boundary
BART
Major Roads and Highways
Data Source: BCDC, MTC, AECOM, BART
1:40,000
0 0.2 0.4 0.8 Miles
* Disclaimer: The inundation 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 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.
Alameda
San Francisco Bay
San Leandro
880


Map 2
Alameda
San Francisco Bay
San Leandro
880
Adapting to Rising Tides
55" Sea Level Rise
Areas potentially exposed to storm event flooding (100-year stillwater)
Areas potentially exposed to wind waves during a storm event
Disconnected Low-lying Areas
ART Project Boundary
BART
Major Roads and Highways
Data Source: BCDC, MTC, AECOM, BART
1:40,000
0 0.2 0.4 0.8 Miles
* 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 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.

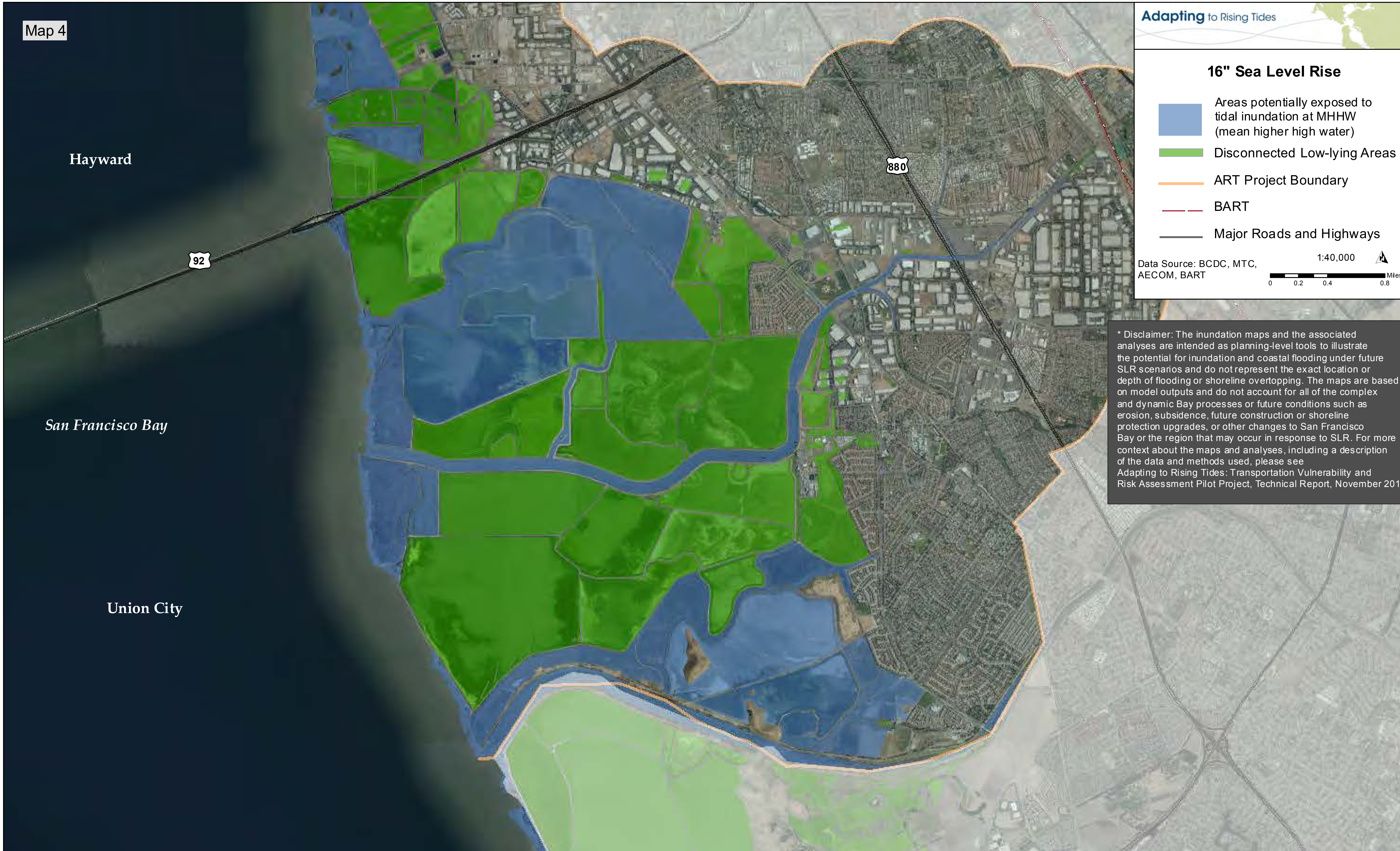

Map 3
San Lorenzo
San Francisco Bay
Hayward
92
880
Adapting to Rising Tides
16" Sea Level Rise
Areas potentially exposed to tidal inundation at MHHW (mean higher high water)
Disconnected Low-lying Areas
ART Project Boundary
BART
Major Roads and Highways
Data Source: BCDC, MTC, AECOM, BART
1:40,000
0 0.2 0.4 0.8 Miles
* 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 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.

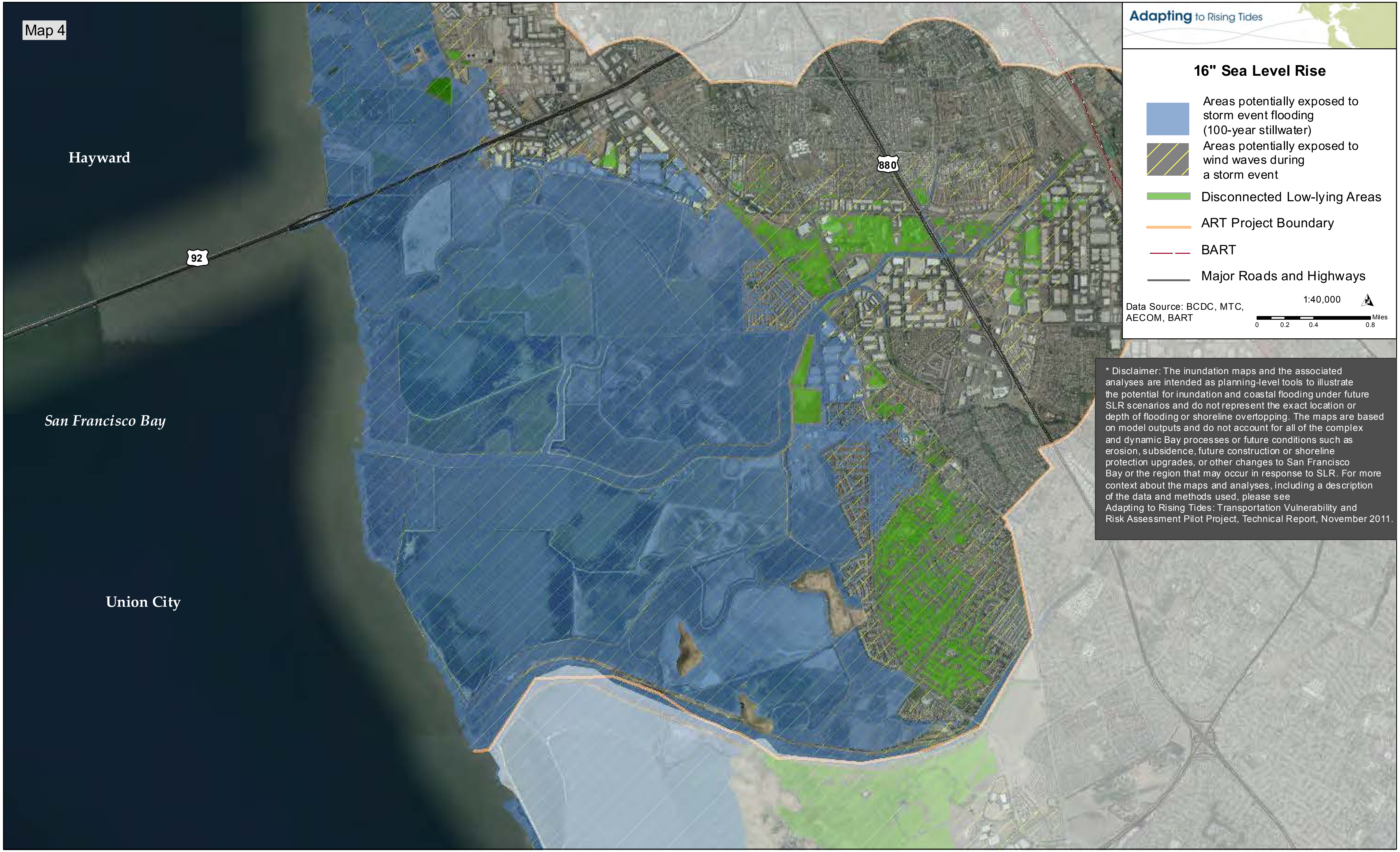

Map 3
Adapting to Rising Tides
16" Sea Level Rise
Areas potentially exposed to storm event flooding (100-year stillwater)
Areas potentially exposed to wind waves during a storm event
Disconnected Low-lying Areas
ART Project Boundary
BART
Major Roads and Highways
Data Source: BCDC, MTC, AECOM, BART
1:40,000
0 0.2 0.4 0.8 Miles
* 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 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.
San Lorenzo
San Francisco Bay
Hayward
92
880


Map 3
Adapting to Rising Tides
55" Sea Level Rise
Areas potentially exposed to tidal inundation at MHHW (mean higher high water)
Disconnected Low-lying Areas
ART Project Boundary
BART
Major Roads and Highways
Data Source: BCDC, MTC, AECOM, BART
1:40,000
0 0.2 0.4 0.8 Miles
* 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 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.
San Lorenzo
San Francisco Bay
Hayward
92
880



Map 3
Adapting to Rising Tides
55" Sea Level Rise
Areas potentially exposed to storm event flooding (100-year stillwater)
Areas potentially exposed to wind waves during a storm event
Disconnected Low-lying Areas
ART Project Boundary
BART
Major Roads and Highways
Data Source: BCDC, MTC, AECOM, BART
1:40,000
0 0.2 0.4 0.8 Miles
San Lorenzo
San Francisco Bay
Hayward
92
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 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.


Map 4
Hayward
92
San Francisco Bay
Union City
880
Adapting to Rising Tides
16" Sea Level Rise
Areas potentially exposed to tidal inundation at MHHW (mean higher high water)
Disconnected Low-lying Areas
ART Project Boundary
BART
Major Roads and Highways
Data Source: BCDC, MTC, AECOM, BART
1:40,000
Miles
0 0.2 0.4 0.8
* 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 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.


Map 4
Hayward
San Francisco Bay
Union City
92
880
Adapting to Rising Tides
16" Sea Level Rise
Areas potentially exposed to storm event flooding (100-year stillwater)
Areas potentially exposed to wind waves during a storm event
Disconnected Low-lying Areas
ART Project Boundary
BART
Major Roads and Highways
Data Source: BCDC, MTC, AECOM, BART
1:40,000
0 0.2 0.4 0.8 Miles
* 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 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.


Map 4
Hayward
San Francisco Bay
Union City
92
880
Adapting to Rising Tides
55" Sea Level Rise
Areas potentially exposed to tidal inundation at MHHW (mean higher high water)
Disconnected Low-lying Areas
ART Project Boundary
BART
Major Roads and Highways
Data Source: BCDC, MTC, AECOM, BART
1:40,000
0 0.2 0.4 0.8 Miles
* 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 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.


Map 4
Hayward
San Francisco Bay
Union City
92
880
Adapting to Rising Tides
55" Sea Level Rise
Areas potentially exposed to storm event flooding (100-year stillwater)
Areas potentially exposed to wind waves during a storm event
Disconnected Low-lying Areas
ART Project Boundary
BART
Major Roads and Highways
Data Source: BCDC, MTC, AECOM, BART
1:40,000
0 0.2 0.4 0.8 Miles
* 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 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.

Analysis of Shoreline Overtopping Potential

For the ART project analysis, "overtopping potential" refers to the condition where the water surface elevation from a particular inundation scenario exceeds the elevation of the existing shoreline, potentially causing flooding of inland low-lying areas. The analysis of overtopping potential identified where the shoreline may not be high enough to control inland inundation relative to the six future climate scenarios evaluated. The analysis did not account for the physics of wave setup and runup, the condition of the shoreline asset, or the potential for the to asset fail due to scour, undermining or a breach after the initial overtopping occurs[3].

The analysis identified the location and depth of inundation at the shoreline, and determined the total length of shoreline that is potentially overtopped. While the analysis informs an understanding of relative vulnerability, even small areas of shoreline overtopping could lead to flooding of large inland areas. And, if the overtopping leads to a structural failure then even larger areas could be inundated at deeper depths. Therefore, the analysis of overtopping potential should be used a screening level tool to help direct resources to specific shoreline areas where further study is necessary and not as a direct indicator of the risk.

Figure 1. Shoreline systems are contiguous reaches that act together to prevent inundation of inland areas. For example, system #9, shown in red, is located at the Martin Luther King Regional Shoreline just south of Arrowhead Marsh.

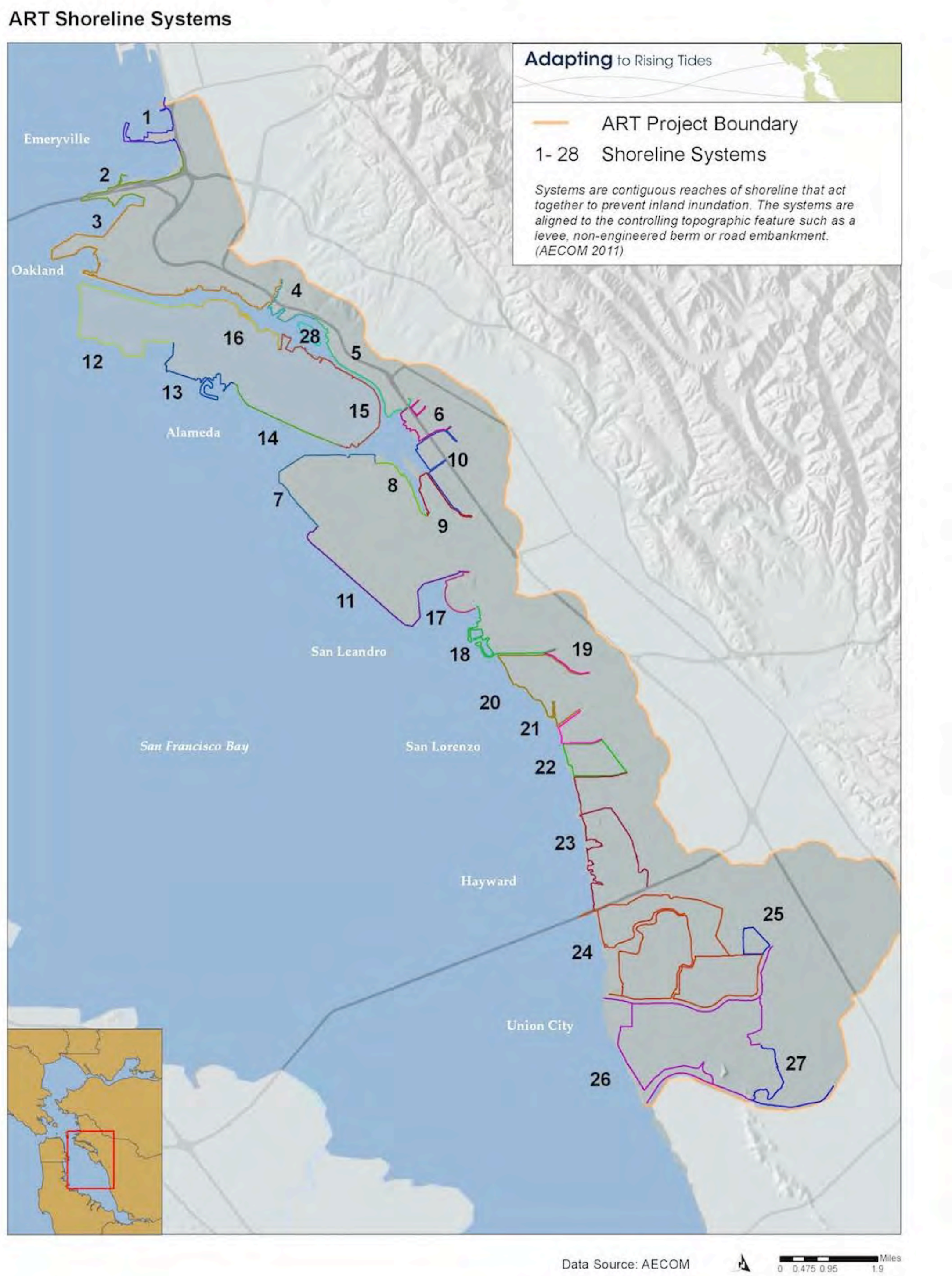
To conduct the overtopping potential analysis the shoreline was subdivided into distinct "systems" (Figure 1). The systems were defined as contiguous reaches of shoreline that act together to prevent inundation of inland areas. The exact location and alignment of each system was based on the topographic feature (based on ground elevation) that would prevent inundation, such as a levee, non-engineered berm or road embankment. In areas where the shoreline was comprised of wetlands and beaches, the system was aligned along an inland topographic feature that acts as a barrier to inland inundation[4].

Depending on the complexity of the shoreline, systems in the ART project area are either comprised of a single shoreline type, such as a reach of levee between two Bay tributaries, or multiple types, a combination of levee, non-engineered berm, and road embankment.

[3] Overtopping potential does not refer to the wave overtopping process, whereby breaking or non-breaking waves reach and overtop a shoreline feature. The depth of inundation due to the 100-year storm with wind waves was determined for shoreline assets but not for inland areas because the physics associated with overland wave propagation and dissipation was beyond the scope of the study.
[4] The analysis did not use wetland or beach systems as the topographic feature because dynamic coastal process such as erosion, organic matter accumulation and sediment deposition/resuspension were not accounted for.

The ART project shoreline was subdivided into 28 systems (Figure 2) with a combined length of 126 miles that represents the complex, and in some areas parallel or redundant features that protect inland areas. The division of the shoreline into the 28 systems was based in part on the scope, scale and objectives of the ART project. In general, the systems are small enough to provide meaningful information about specific shoreline vulnerabilities and risk, but are few enough in number to be manageable for the entire project area.

Figure 2. The 28 shoreline systems identified in the ART project area.



The overtopping potential analysis identified specific locations within each system that could be overtopped by the six future climate scenarios. The results of the analysis both inform both an understanding of the relative sensitivity of each system and the likelihood that an inland area protected by a specific shoreline system could be exposed. Based on the uncertainty of the topographic data and the modeling results, only areas overtopped by depths of 0.5 feet or greater were included in the analysis. Specific details on the methods of the overtopping potential analysis are included in Appendix B.

A summary of the overtopping potential results is provided below. Overtopping potential metrics were calculated for each system, and in some cases are summarized for the entire project area. These metrics include: **length of the shoreline overtopped**, the **percent of the shoreline length overtopped**, and the **average and maximum depth of overtopping**.

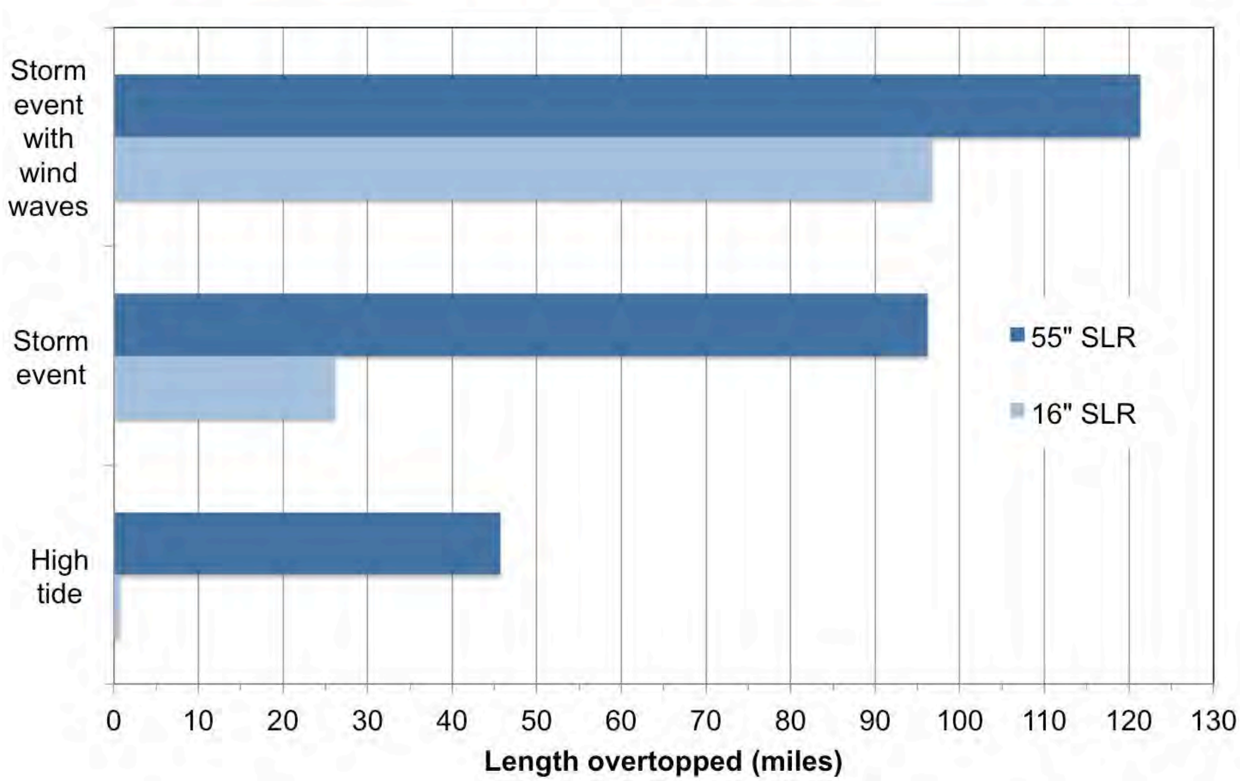
Length Overtopped

The length of shoreline overtopped within each system helps inform analysis of the likelihood that assets protected by the system would be exposed to sea level rise and storm events. It is also an indication of how vulnerable the shoreline system is to a future climate impact. For example, assets protected by a system with 1,000 feet of overtopping have a greater likelihood of exposure than those protected by a system with 10 feet of overtopping. Similarly, a system that has a greater length of overtopping is more vulnerable than one with less overtopping. As the exposure to overtopping increases across a system the potential for erosion, scour, and failure will increase, and the capacity to quickly, easily or in a low-cost manner either modify the system or improve its ability to accommodate the impact will diminish.

Approximately one mile of shoreline will be overtopped with 16 inches of sea level rise at high tide. This overtopping will occur mostly within two systems: #2 on the north side of the San Francisco-East Bay Bridge peninsula, and #23 at the Hayward Regional Shoreline (Figure 2). During a storm event with 16 inches of sea level rise, the total length of shoreline overtopped increases to 28 miles, with overtopping occurring in all but one system (#19). With the addition of wind waves during the storm event, all of the systems are overtopped, and the length of overtopping more than triples to a total of 97 miles (Figure 3).

With 55 inches of sea level rise all 28 systems are overtopped for each Bay water level evaluated. A total of 46 miles are overtopped at high tide, 96 miles during a storm event, and 121 miles during a storm event with wind waves (Figure 3).

Figure 3. Total length of shoreline system overtopped by the six future climate scenarios evaluated. The total length of project shoreline systems is 126 miles.



Percent of Length Overtopped
Because the length of each system varies widely, from 1.2 to 18 miles[5], it is important to also consider overtopping relative to system length. The chosen metric, the percent of the length overtopped, is an indication of the relative amount of exposure potentially experienced within each system.

Only 1% of the shoreline will overtop with 16 inches of sea level rise at high tide (Figure 4). Of the fourteen systems overtopped by this scenario, only three are greater than 1% overtopped (#2, 4, and 23, Figure 5). During a storm event, the percent length overtopped increases to 21%. More than half of the systems will have less than 50% of their length overtopped, and only one system (#8) will have greater than 75% of its length overtopped. With the addition of wind waves during the storm event the percent of length overtopped increases dramatically to 77%, with the majority of systems having 75% of their overtopped and only one system (#17) having less than 10% of its length overtopped.

With 55 inches of sea level rise at high tide, 36% of the shoreline will overtop. Only four systems will have less than 10% of their length overtopped (#11, 14, 17 and 19). During a storm event the percent of length overtopped increases to 76%, and if there are wind waves nearly all of the shoreline is overtopped (96%). Only one system (#27) has less than 75% of its length overtopped (54%) during a storm with wind waves (Figure 4 and 5).

[5] The shortest system, #19 (1.2 miles), is in San Leandro, and the longest, #24 (18 miles), is in Hayward.

Figure 4. The percent length overtopped on average for the 28 ART project shoreline systems by the six future climate scenarios evaluated.

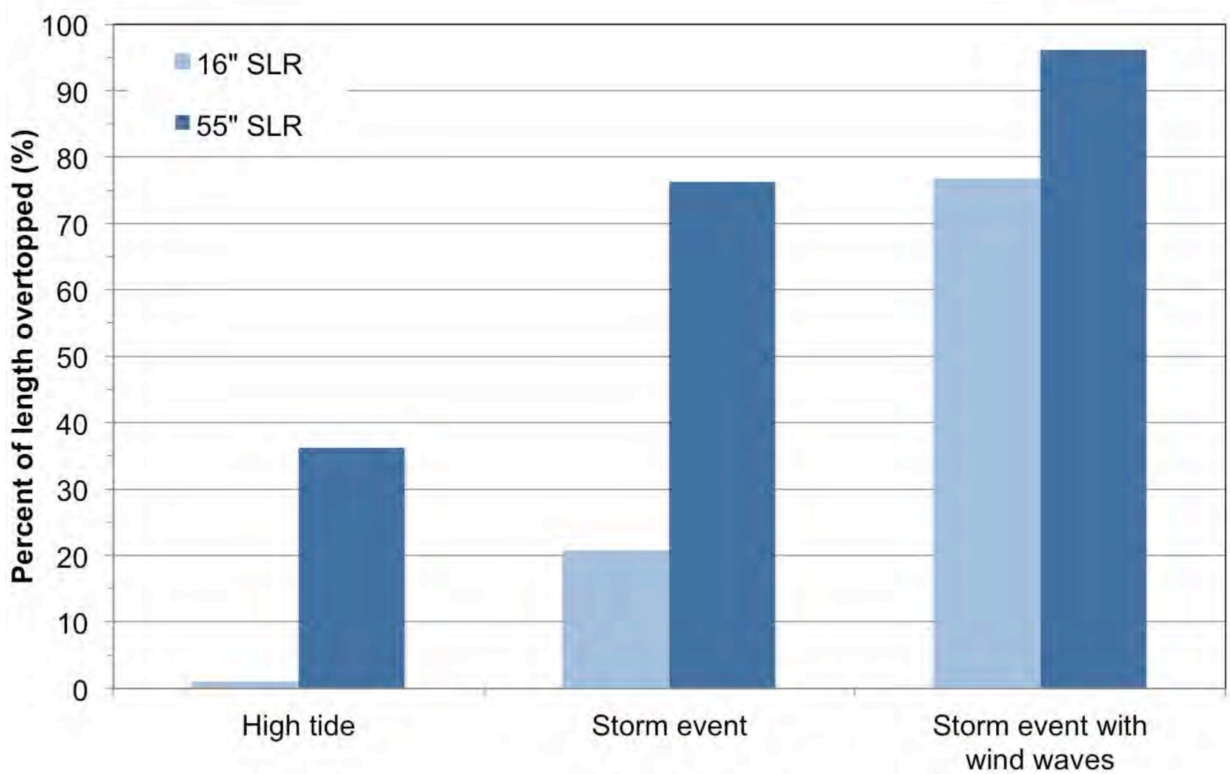
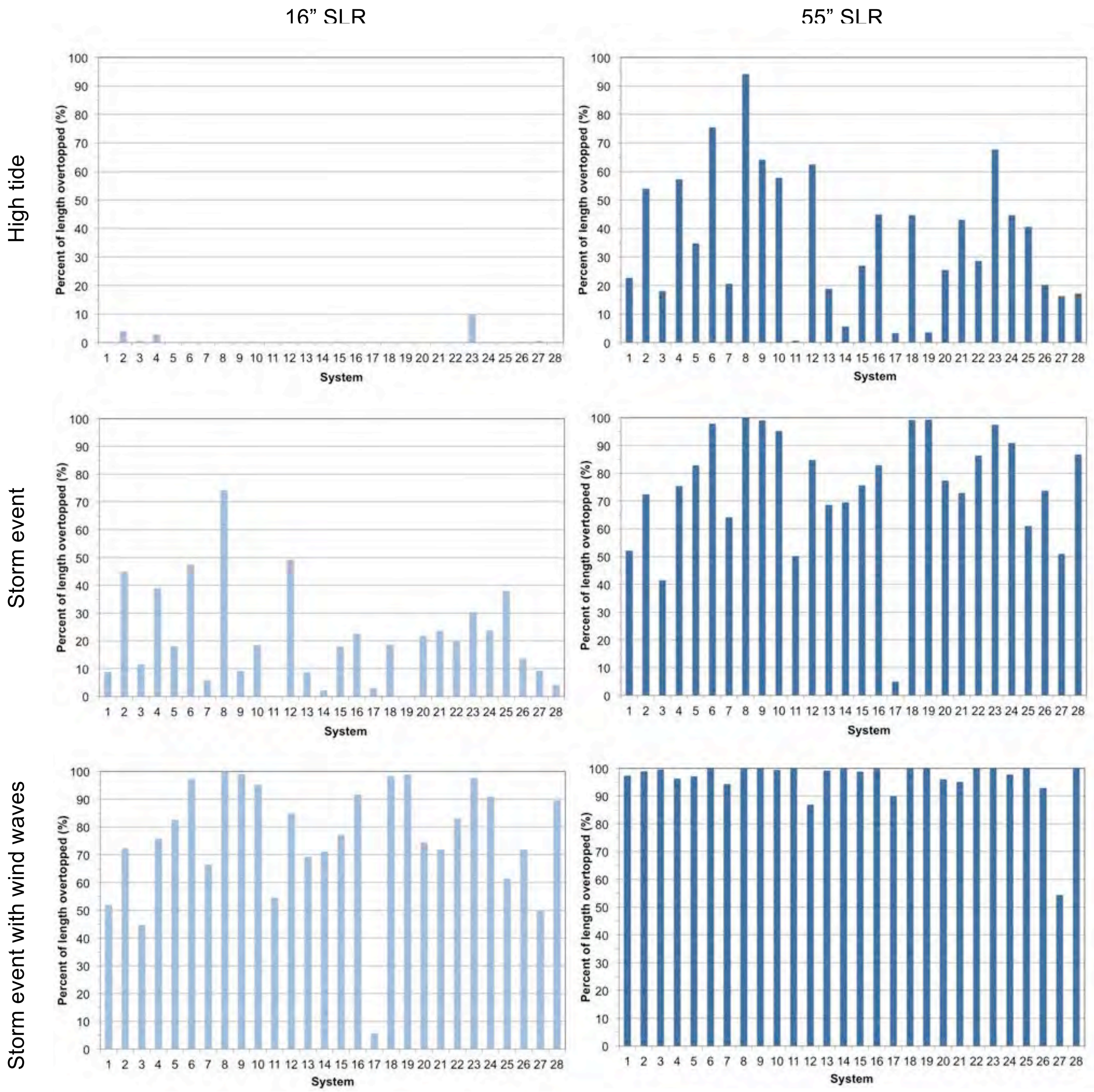


Figure 5. Percent length overtopped for each system by the six future climate scenarios evaluated.



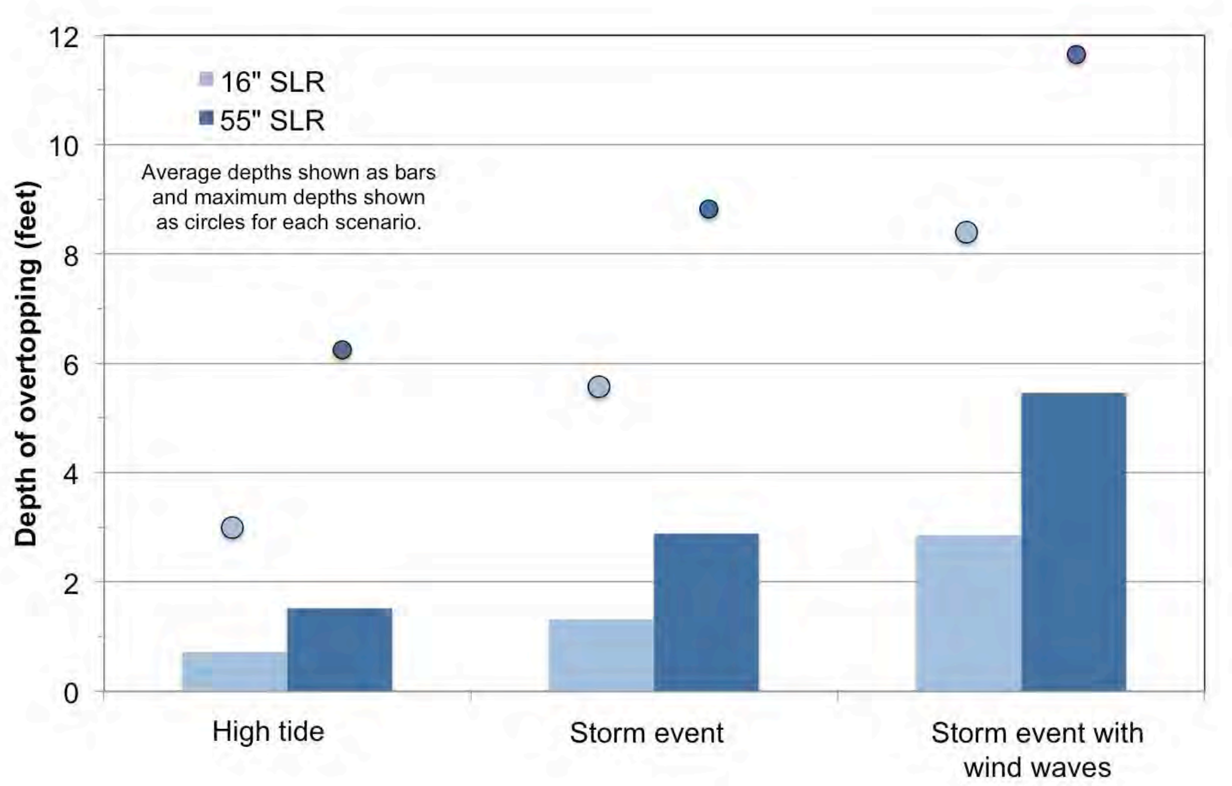
Average and Maximum Depth of Overtopping

The potential overtopping within a shoreline system is a useful screening-level tool that informs an understanding of the specific locations where additional study is necessary. To better understand where further efforts should be focused[6], and to more clearly define where the likelihood of an impact to inland areas could be, a segment level analysis was completed that determined the specific location(s) of potential overtopping along the shoreline. The analysis was summarized for each system as the average and maximum depth of overtopping that could occur due to the six future climate scenarios evaluated.

Across all 28 systems, the average depth of overtopping with 16 inches of sea level rise at high tide is less than one foot (Figure 6). During a storm event, the average depth increases to slightly more than 1 foot, and with wind waves to almost 3 feet. The maximum overtopping depths observed across all 28 systems occur within system #23 (Figure 2), with potentially 3 feet at high tide, 6 feet during a storm event, and 8 feet during a storm event with wind waves.

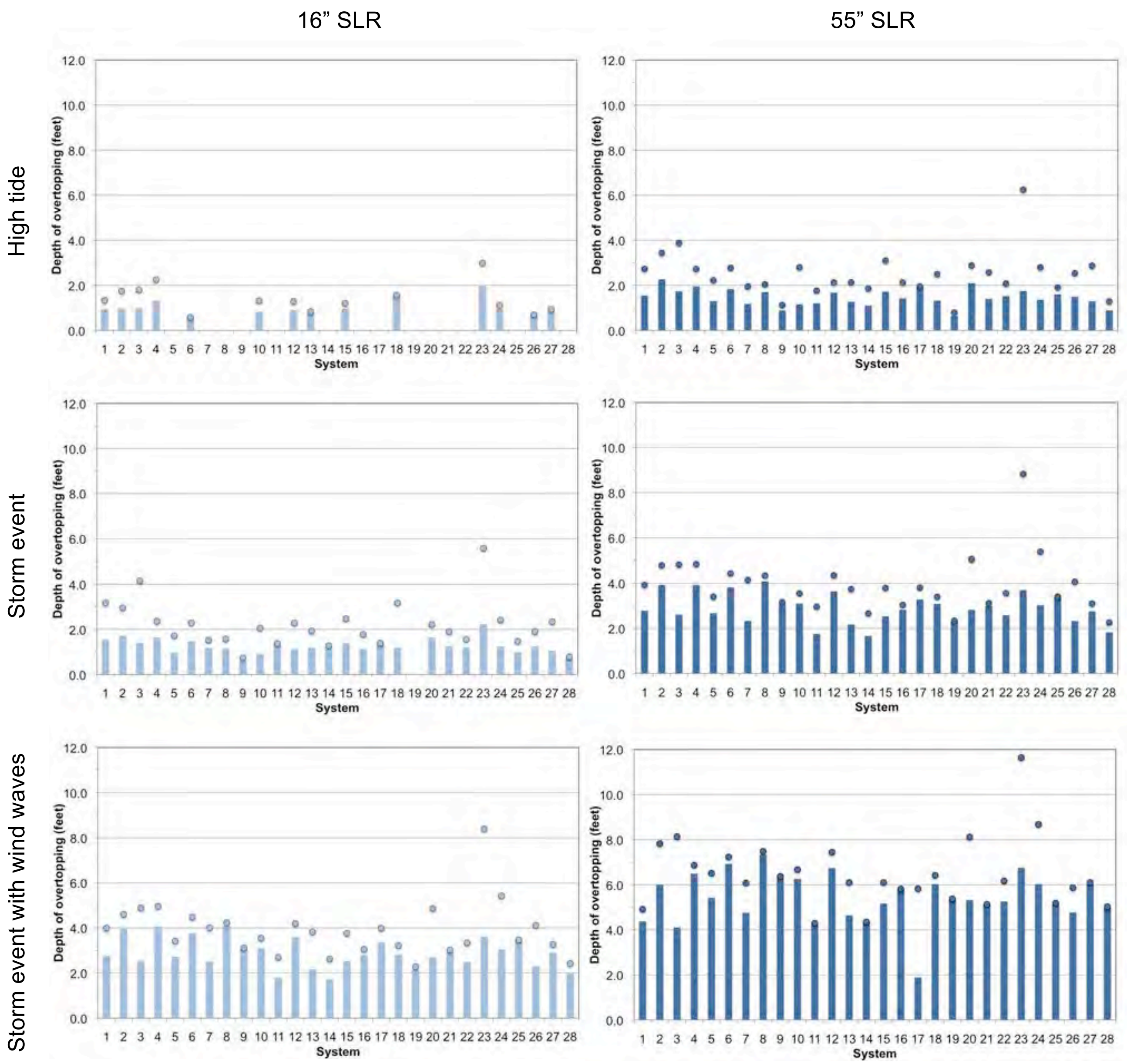
With 55 inches of sea level rise the majority of systems are overtopped on average by 1.5 feet at high tide, while during a storm event the average depth doubles to almost 3 feet. If there are wind waves during the storm event the average depth of overtopping increases to 5.5 feet. The maximum overtopping depths observed also occur within system #23, with potentially 6 feet at high tide, 9 feet with a storm event, and 12 feet during a storm event with wind waves.

Figure 6. Average (bars) and maximum (circles) depth of overtopping across the 28 ART project shoreline systems for the six future climate scenarios evaluated.

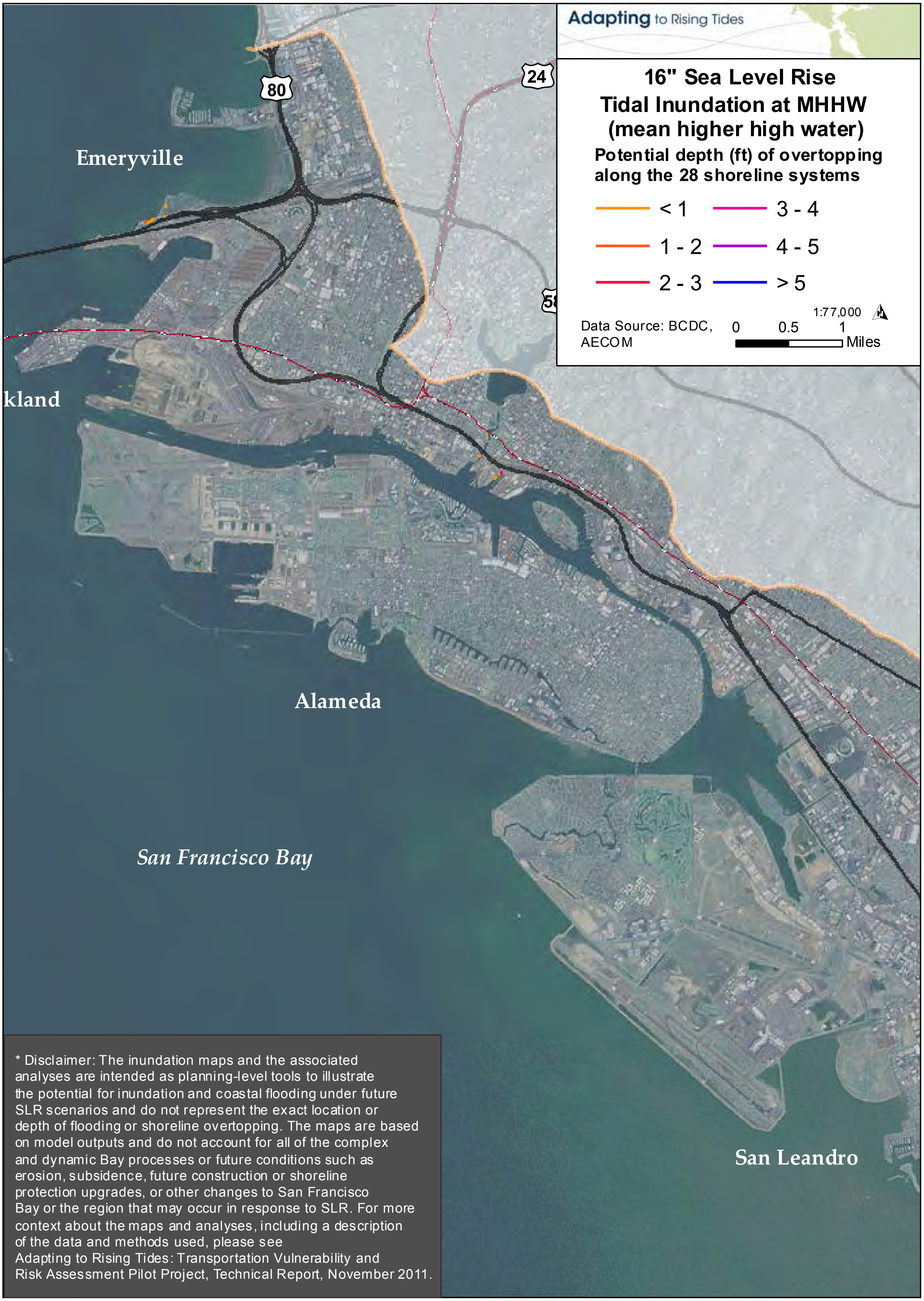


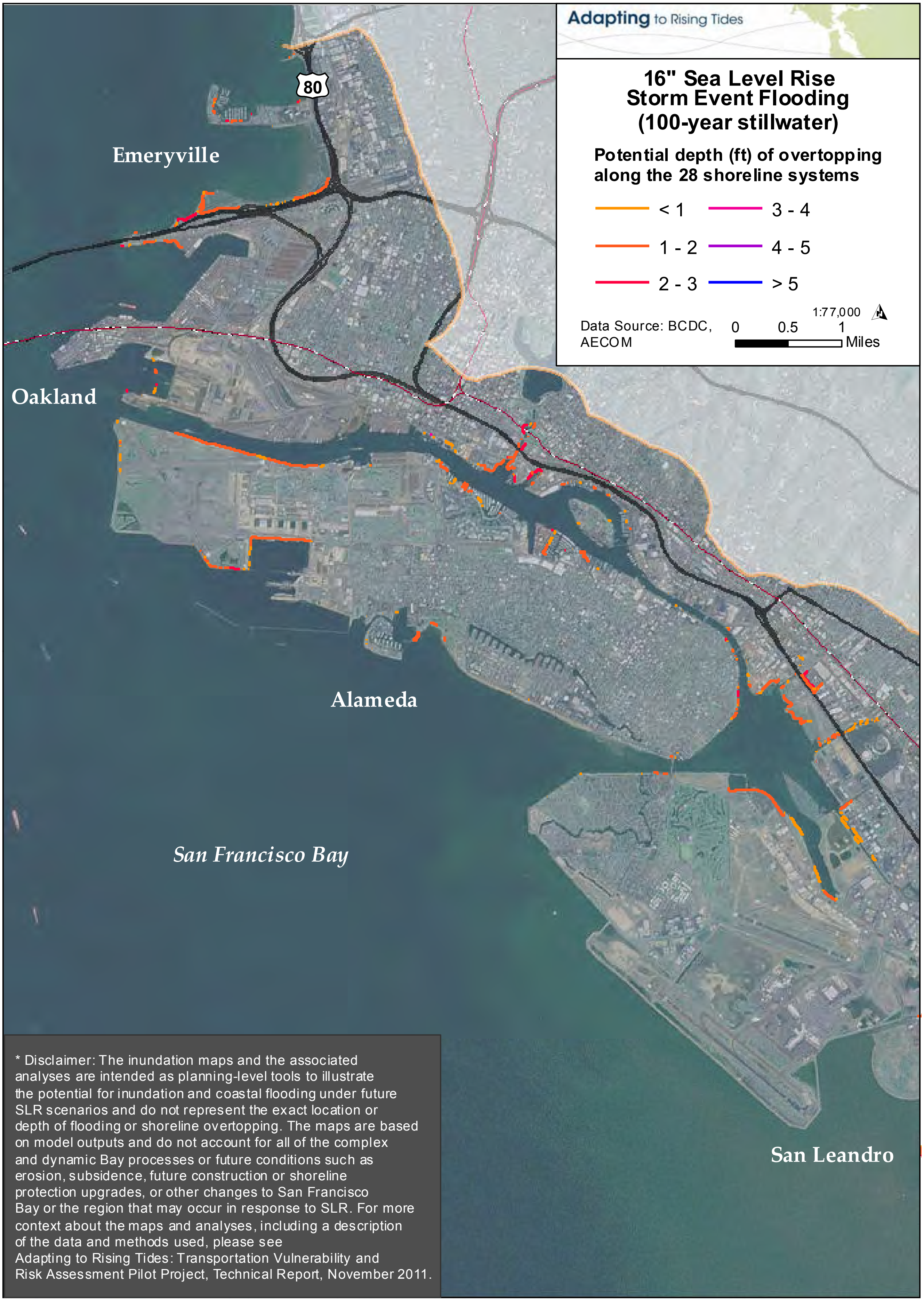
[6] See Chapter 6, Structural Shorelines, for specific examples of how the segment-level analysis was used to understand vulnerability and risk of representative shoreline areas.

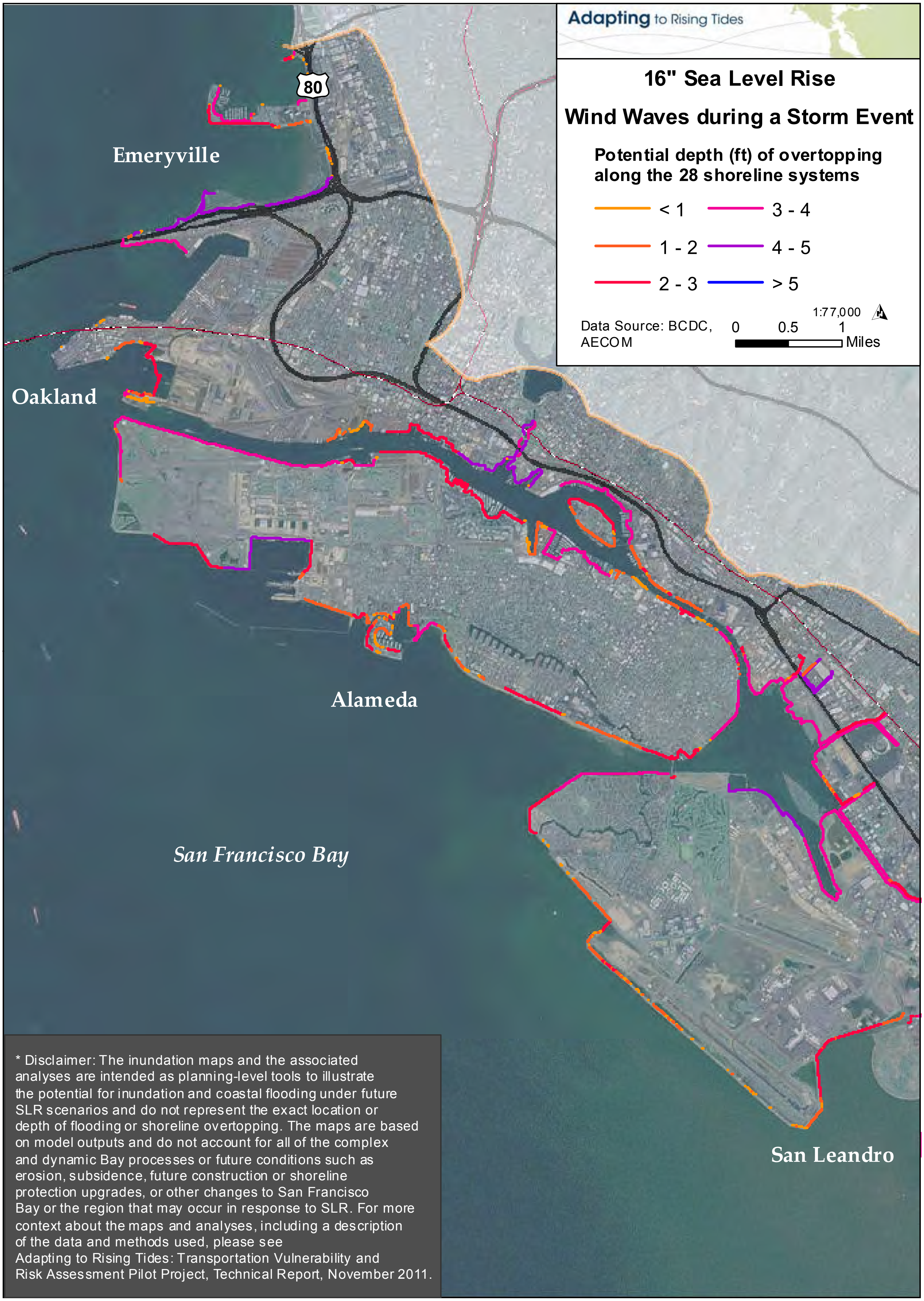
Figure 7. Average (bars) and maximum (circles) depth of overtopping within each system for the six future climate scenarios evaluated.

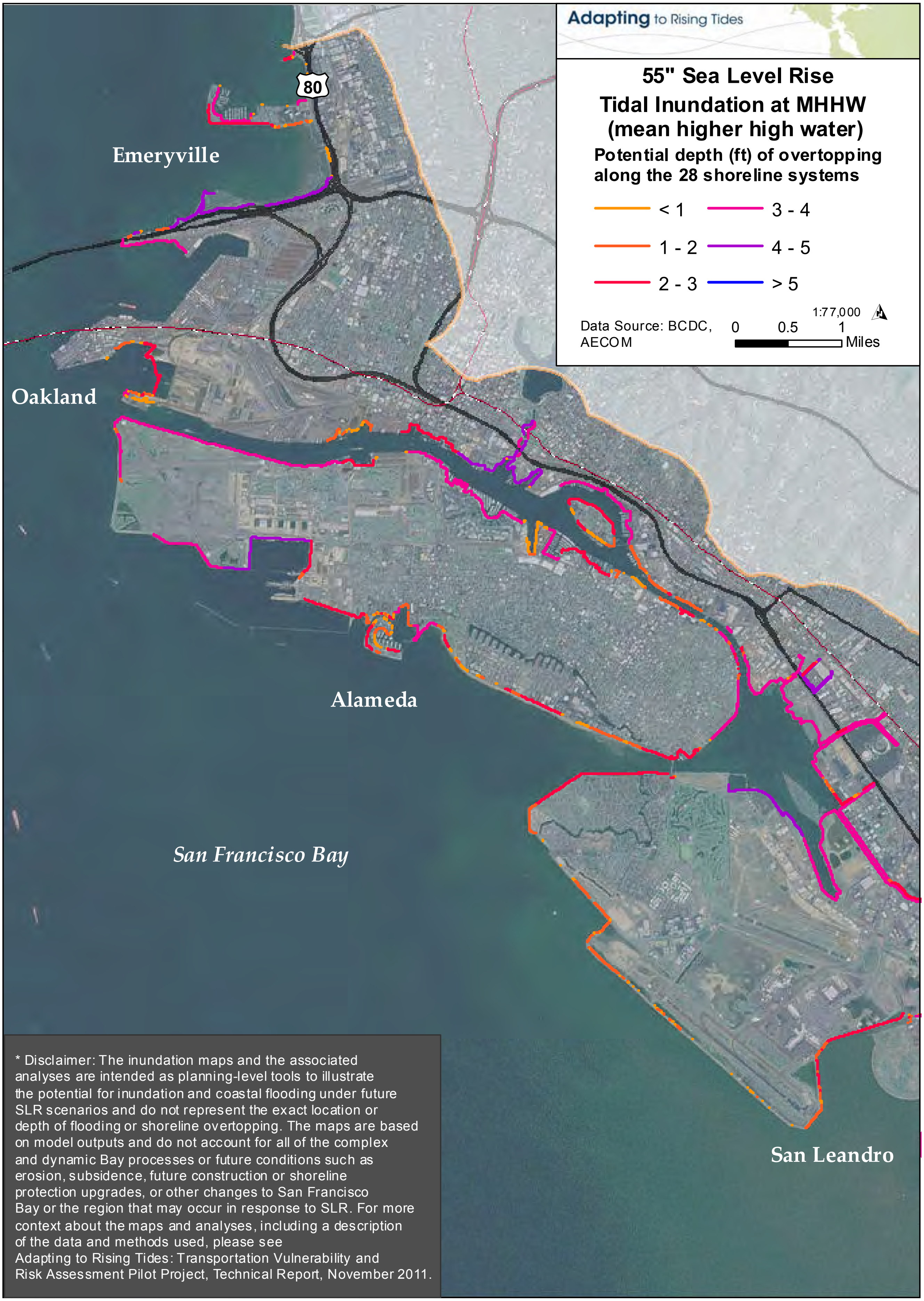


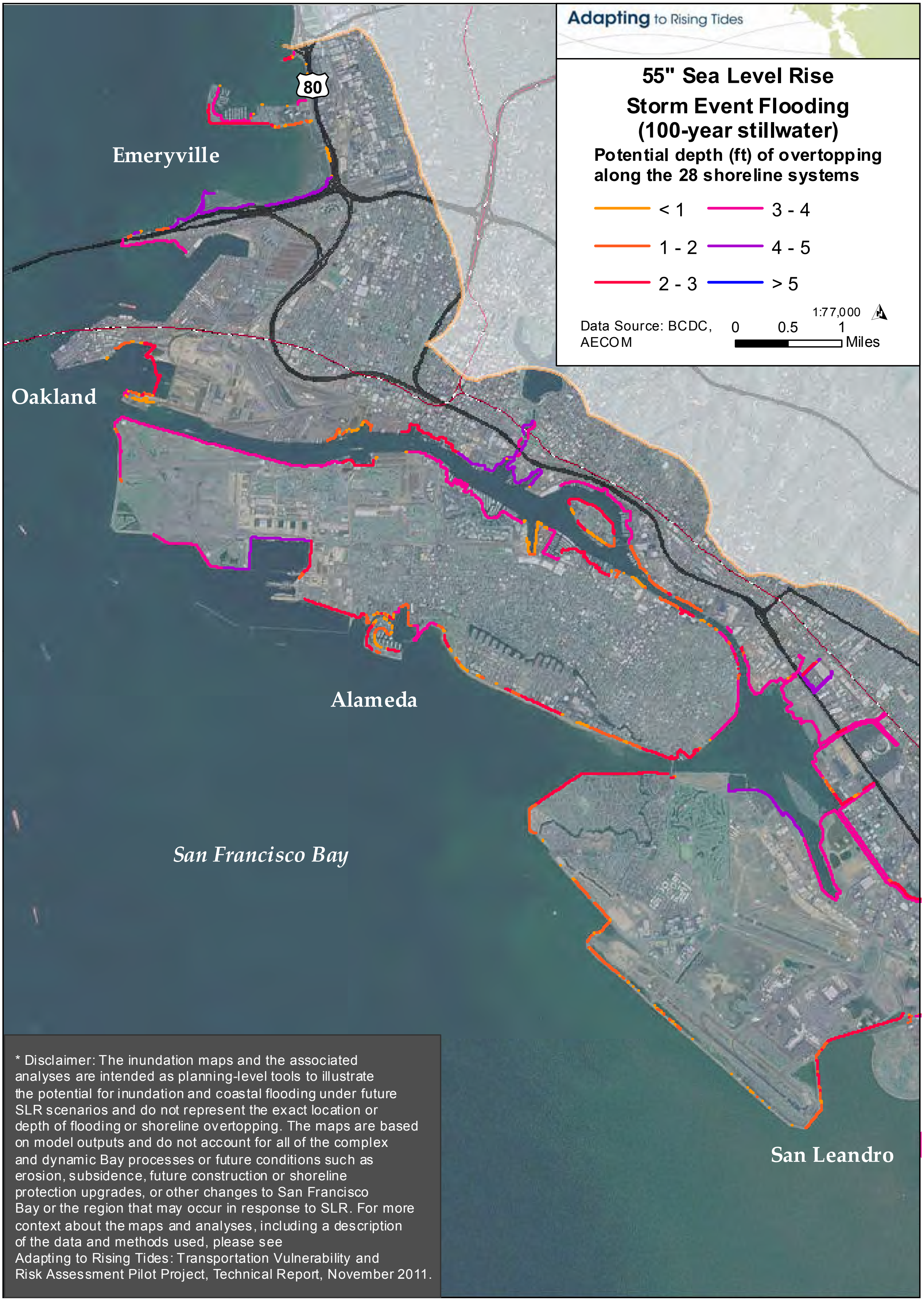
Maps Depicting Average Depth of Potential Overtopping

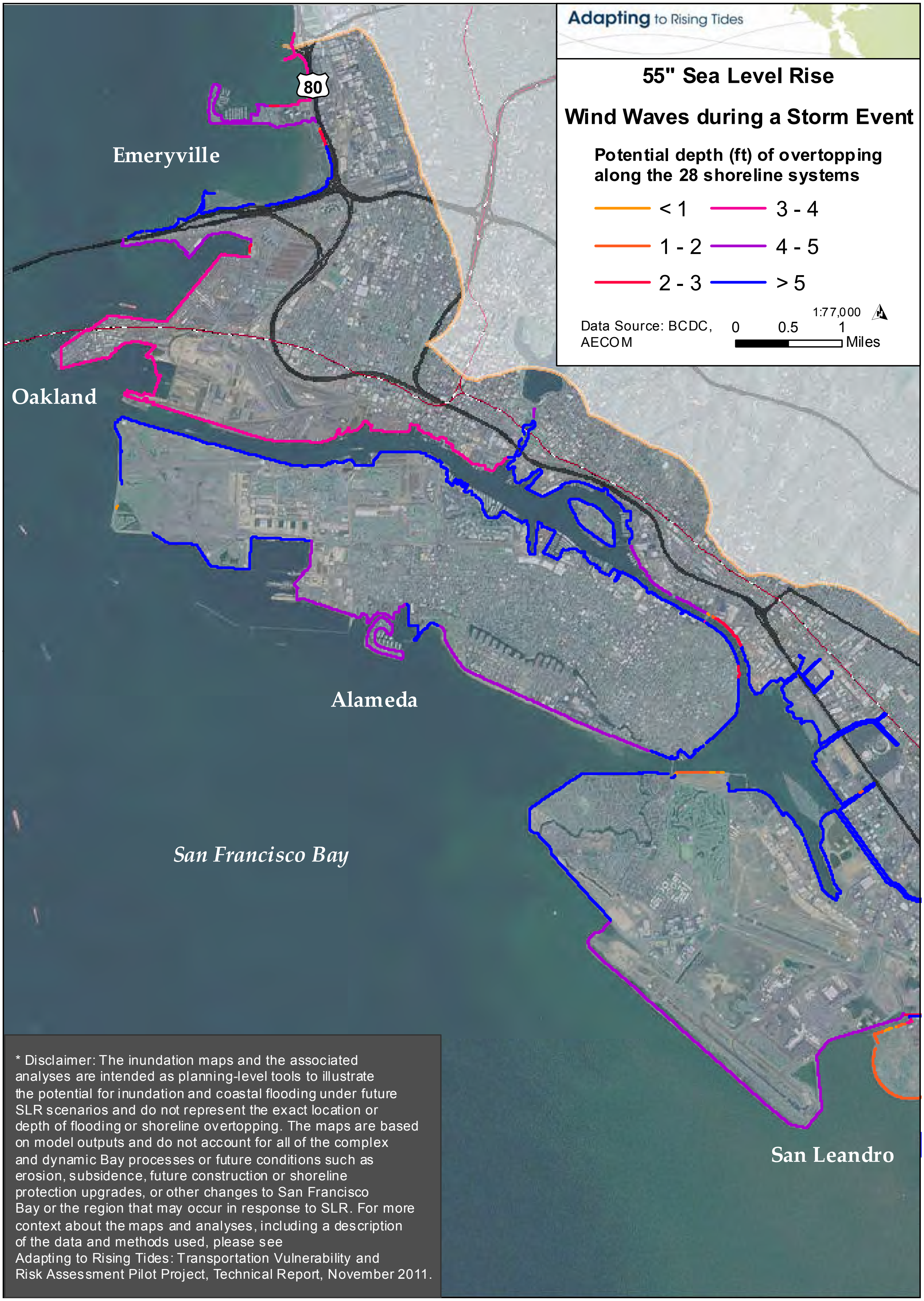

Adapting to Rising Tides
16" Sea Level Rise
Tidal Inundation at MHHW
(mean higher high water)
Potential depth (ft) of overtopping along the 28 shoreline systems
< 1
3 - 4
1 - 2
4 - 5
2 - 3
> 5
1:77,000
Data Source: BCDC, AECOM
0 0.5 1 Miles
80
24
Emeryville
kland
Alameda
San Francisco Bay
San Leandro
* 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 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.

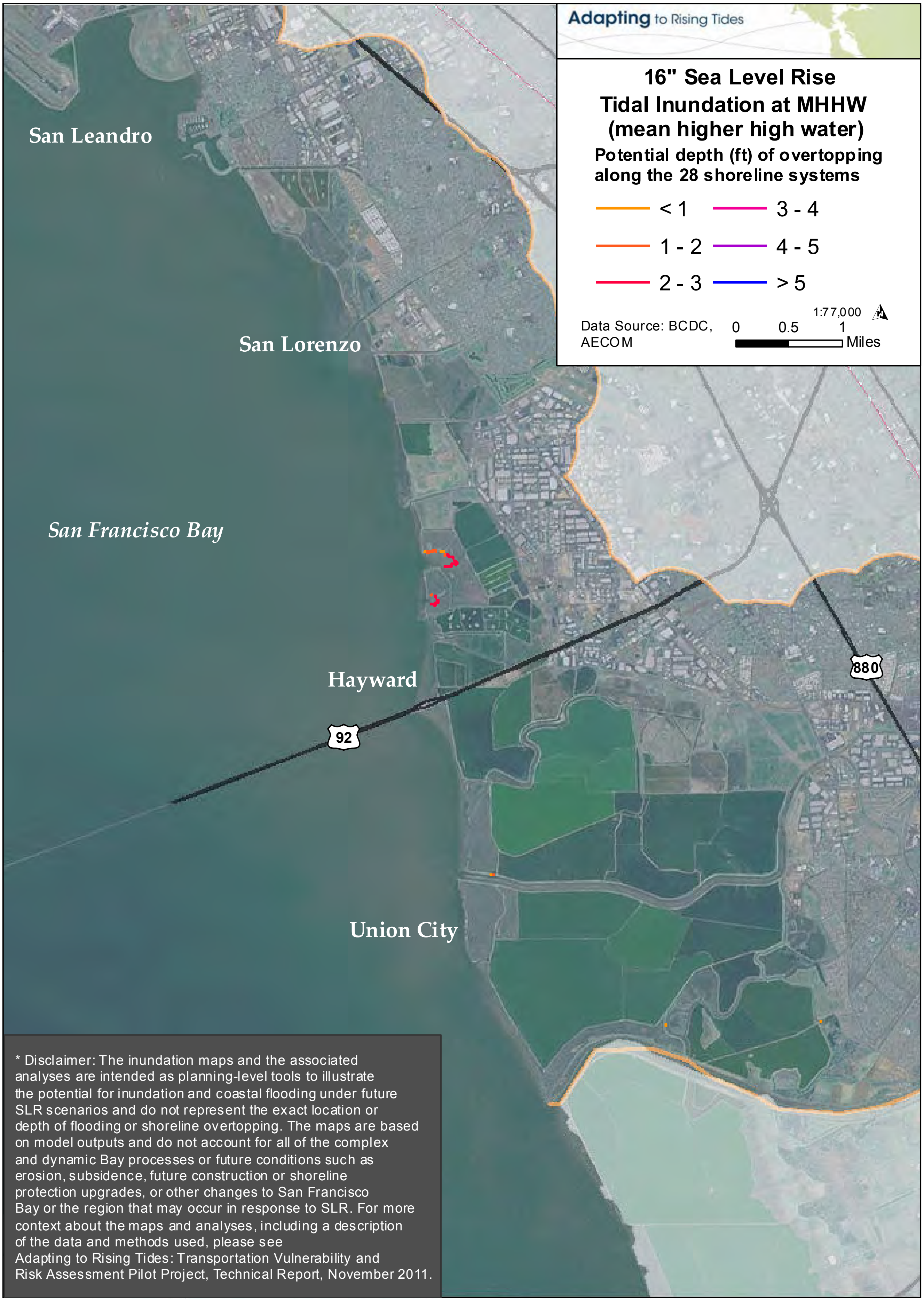

Adapting to Rising Tides
16" Sea Level Rise
Storm Event Flooding
(100-year stillwater)
Potential depth (ft) of overtopping along the 28 shoreline systems
< 1
3 - 4
1 - 2
4 - 5
2 - 3
> 5
Data Source: BCDC, AECOM
1:77,000
0
0.5
1
Miles
80
Emeryville
Oakland
Alameda
San Francisco Bay
San Leandro
* Disclaimer: 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 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.

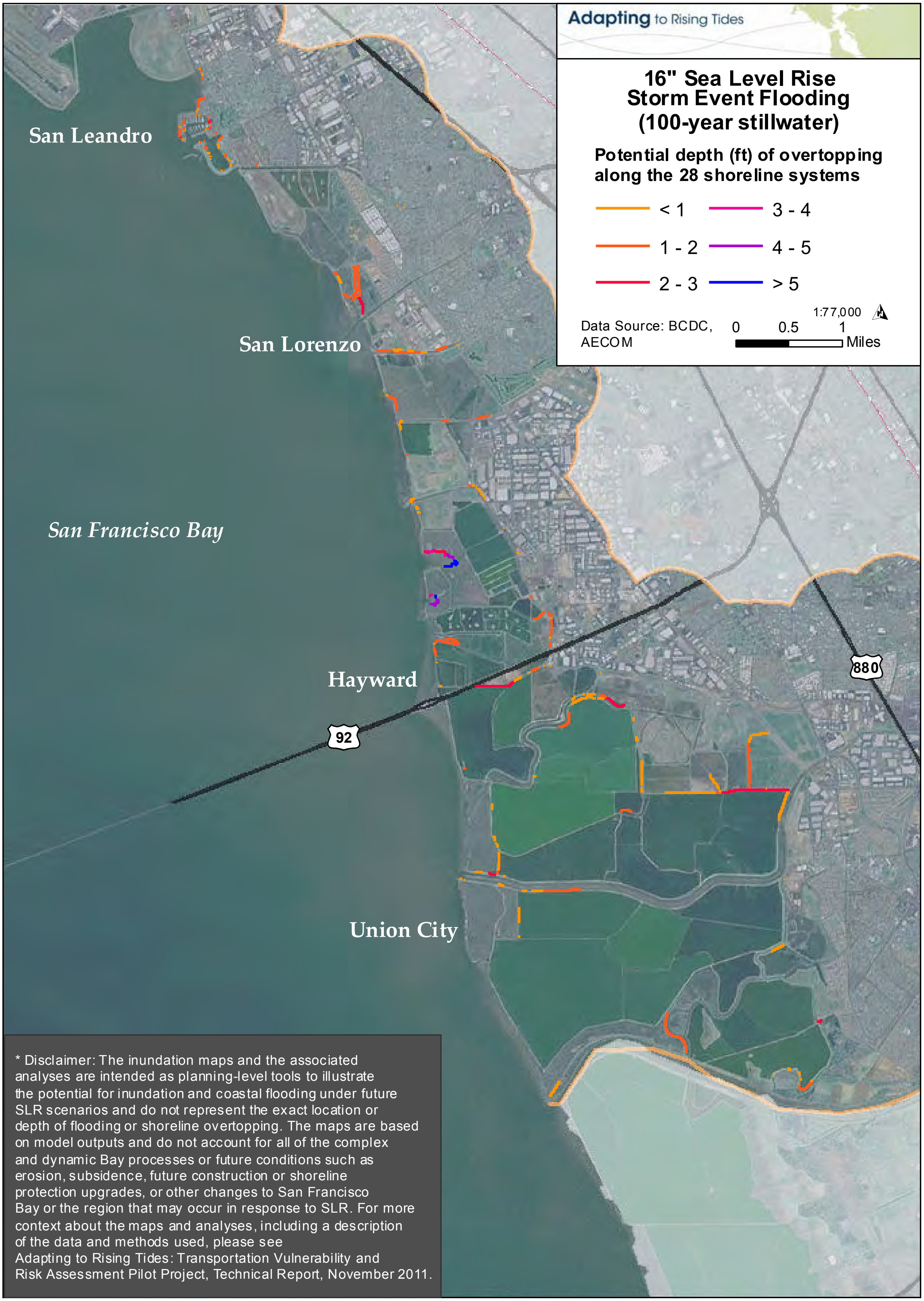

Adapting to Rising Tides
16" Sea Level Rise
Wind Waves during a Storm Event
Potential depth (ft) of overtopping along the 28 shoreline systems
< 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Data Source: BCDC, AECOM
1:77,000
0 0.5 1 Miles
80
Emeryville
Oakland
Alameda
San Francisco Bay
San Leandro
* Disclaimer: The 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 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
55" Sea Level Rise
Tidal Inundation at MHHW
(mean higher high water)
Potential depth (ft) of overtopping along the 28 shoreline systems
< 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Data Source: BCDC, AECOM
1:77,000
0 0.5 1 Miles
80
Emeryville
Oakland
Alameda
San Francisco Bay
San Leandro
* 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 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.

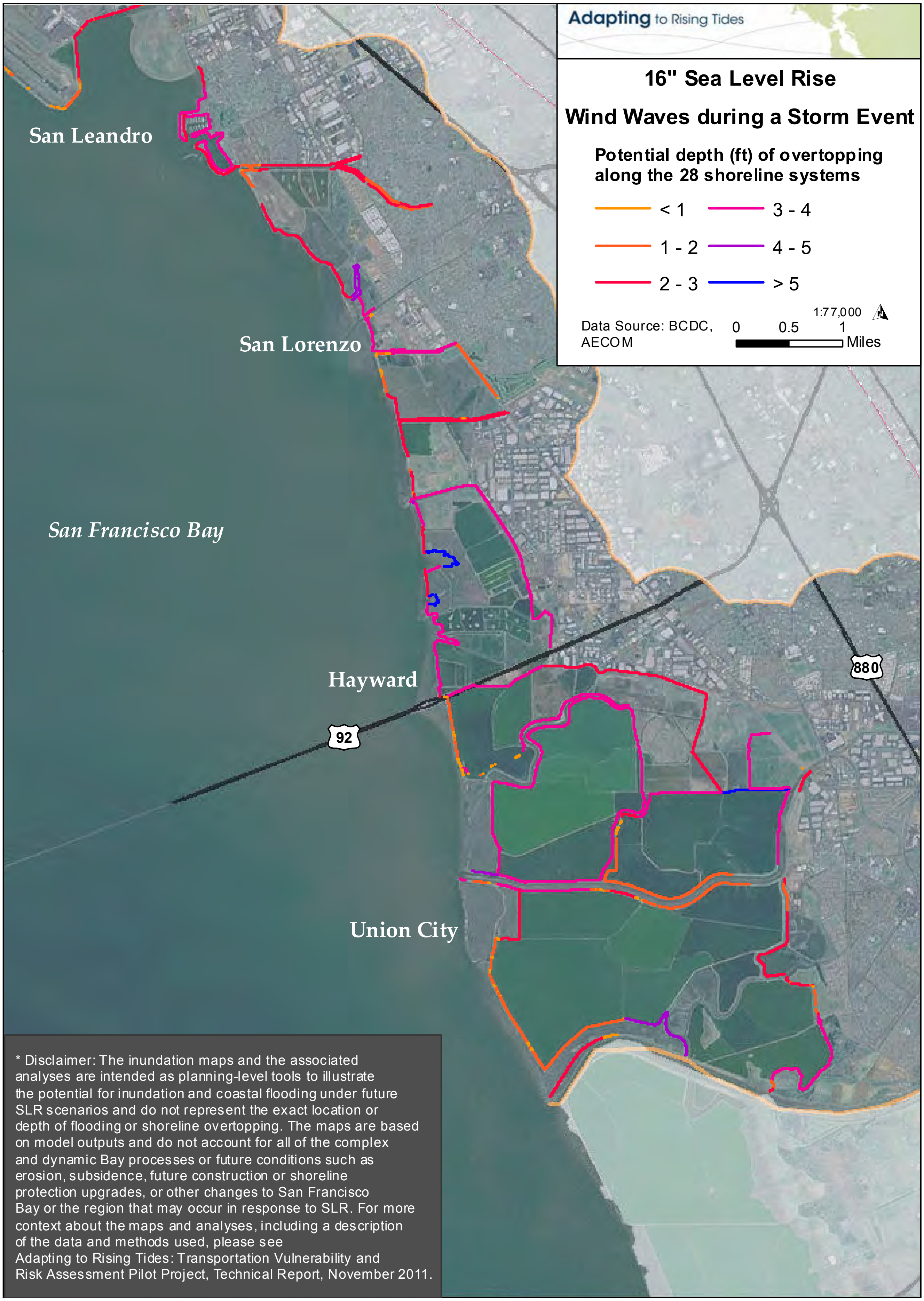

Adapting to Rising Tides
55" Sea Level Rise
Storm Event Flooding
(100-year stillwater)
Potential depth (ft) of overtopping along the 28 shoreline systems
< 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
1:77,000
Data Source: BCDC, AECOM
0 0.5 1 Miles
80
Emeryville
Oakland
Alameda
San Francisco Bay
San Leandro
* Disclaimer: 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 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.

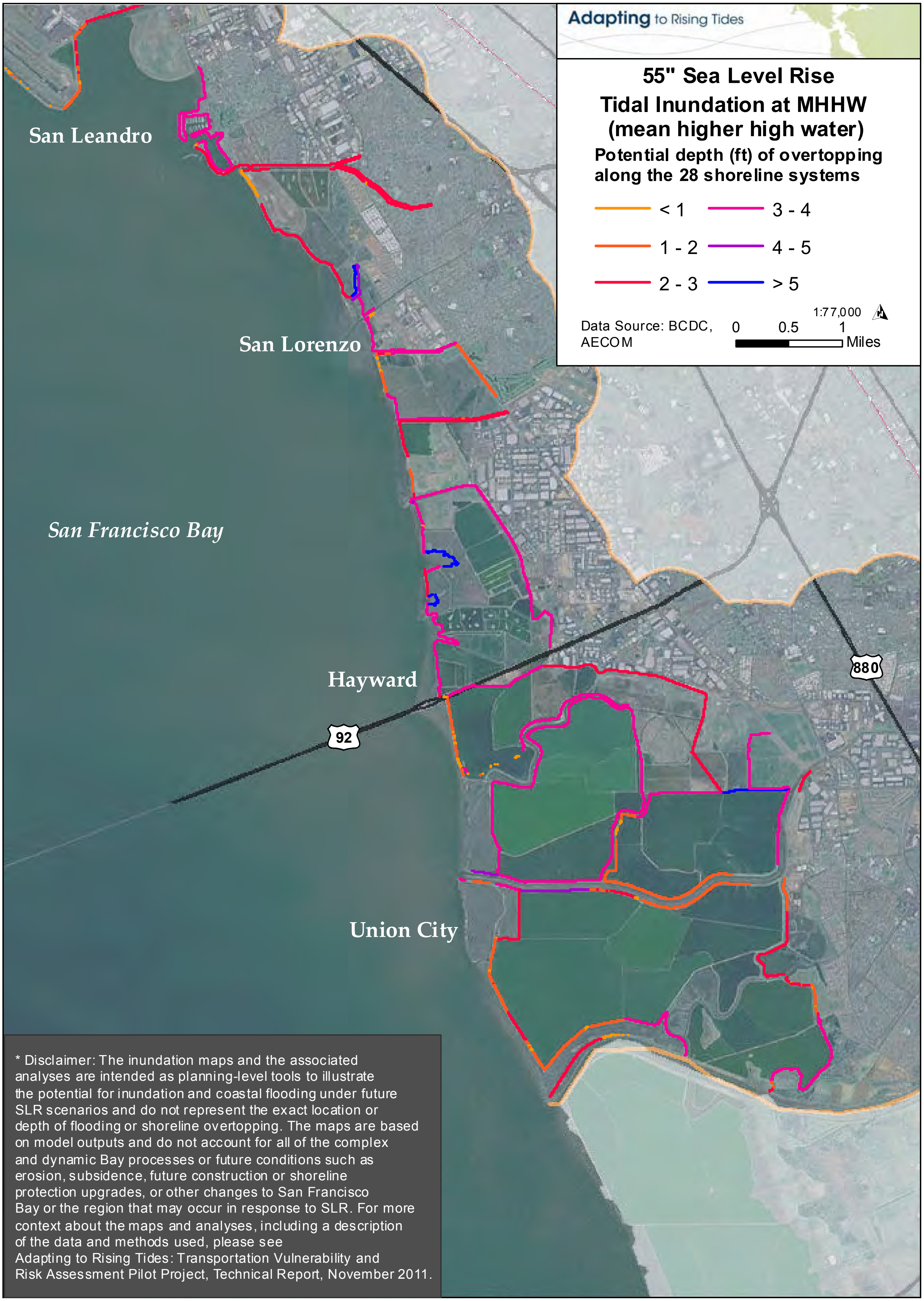

Adapting to Rising Tides
55" Sea Level Rise
Wind Waves during a Storm Event
Potential depth (ft) of overtopping along the 28 shoreline systems
< 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Data Source: BCDC, AECOM
1:77,000
0 0.5 1 Miles
80
Emeryville
Oakland
Alameda
San Francisco Bay
San Leandro
* Disclaimer: The 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 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.

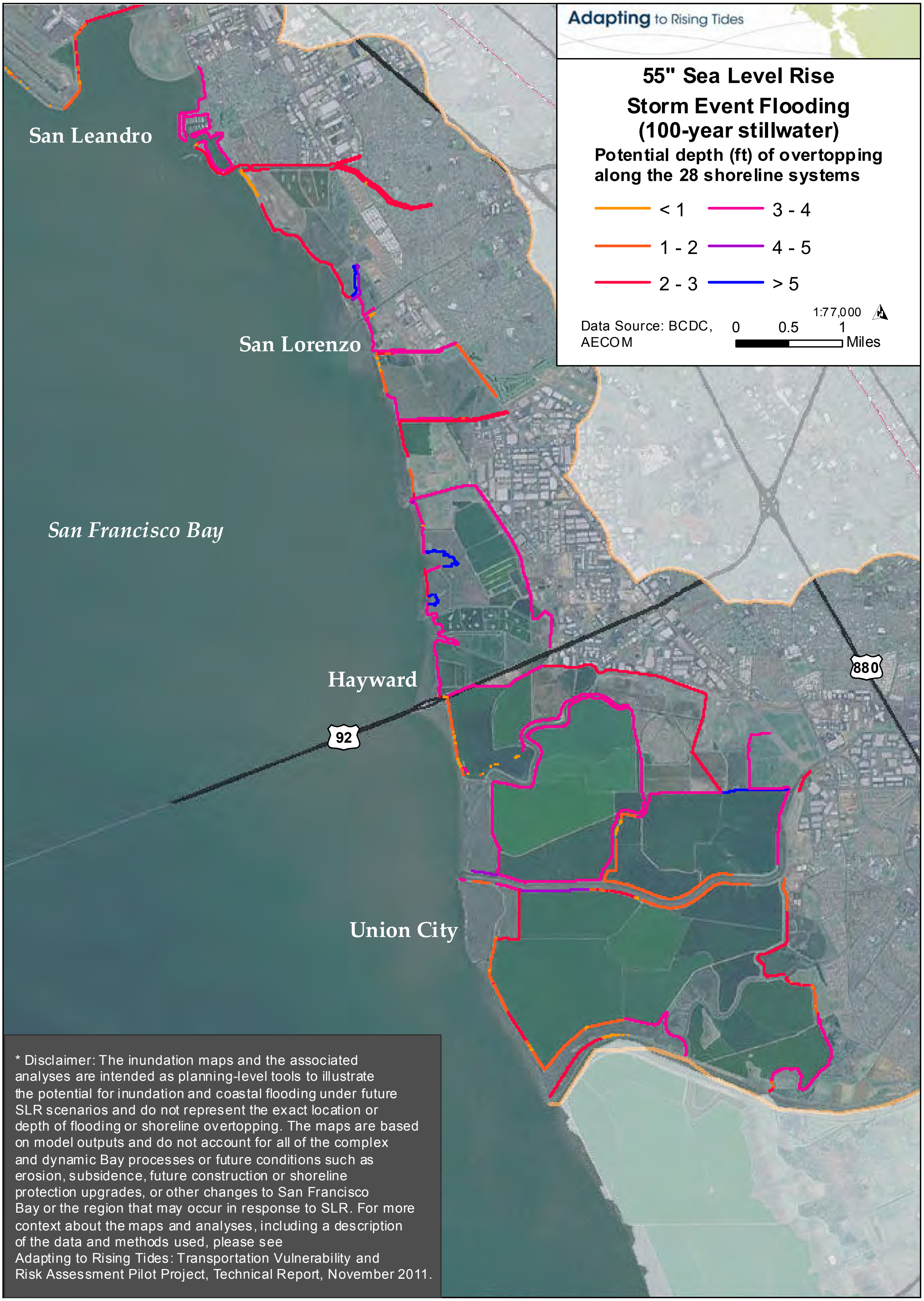

Adapting to Rising Tides
16" Sea Level Rise
Tidal Inundation at MHHW
(mean higher high water)
Potential depth (ft) of overtopping along the 28 shoreline systems
< 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Data Source: BCDC, AECOM
1:77,000
0 0.5 1 Miles
San Leandro
San Lorenzo
San Francisco Bay
Hayward
Union City
92
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 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.

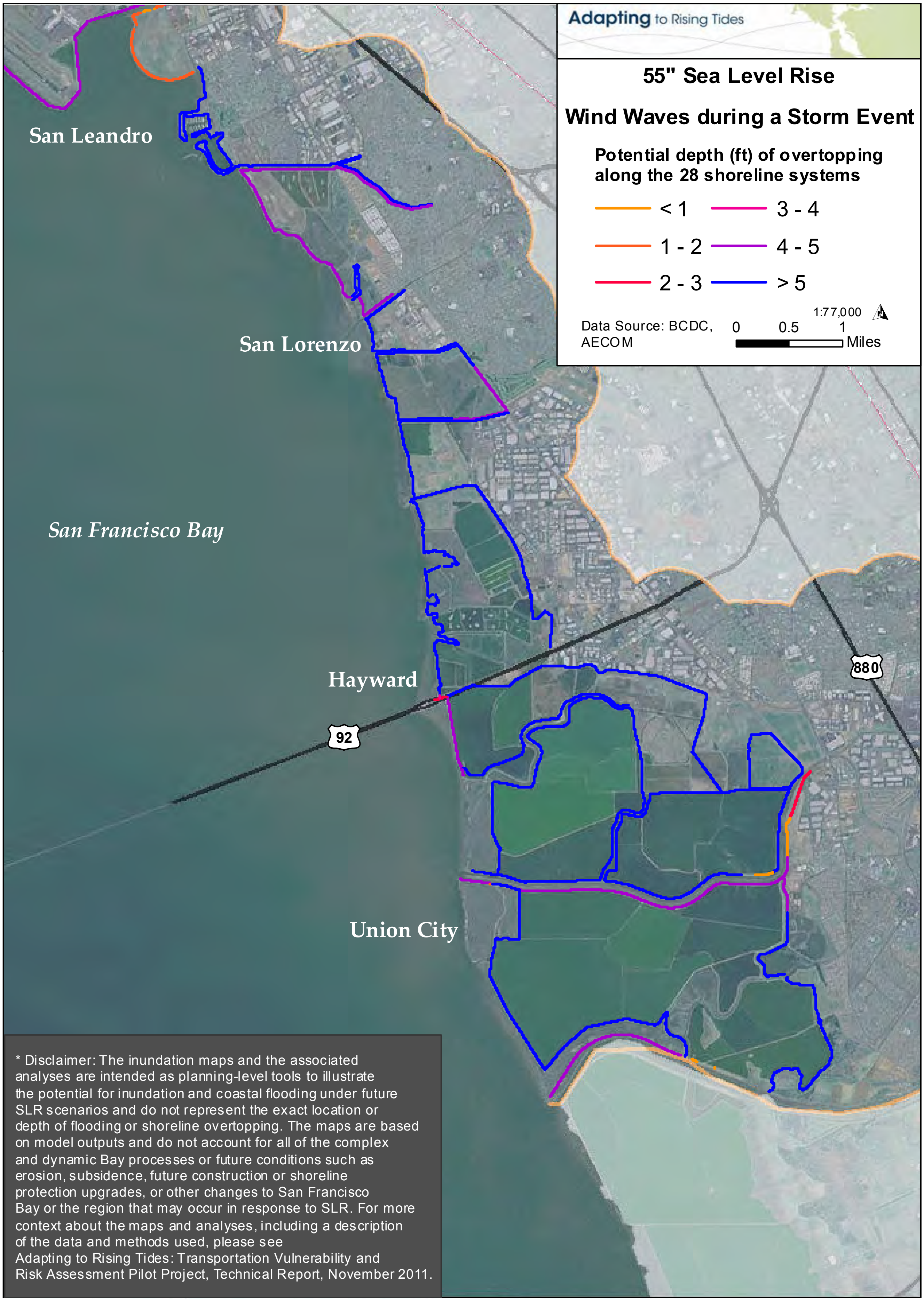


* Disclaimer: The inundation maps and the associated analyses are intended as planning-level tools to illustrate the potential for inundation and coastal flooding under future SLR scenarios and do not represent the exact location or depth of flooding or shoreline overtopping. The maps are based on model 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
16" Sea Level Rise
Wind Waves during a Storm Event
Potential depth (ft) of overtopping along the 28 shoreline systems
< 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Data Source: BCDC, AECOM
1:77,000
0 0.5 1
Miles
San Leandro
San Lorenzo
San Francisco Bay
Hayward
92
880
Union City
* 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 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
55" Sea Level Rise
Tidal Inundation at MHHW
(mean higher high water)
Potential depth (ft) of overtopping along the 28 shoreline systems
< 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Data Source: BCDC, AECOM
1:77,000
0 0.5 1 Miles
San Leandro
San Lorenzo
San Francisco Bay
Hayward
Union City
92
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 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
55" Sea Level Rise
Storm Event Flooding
(100-year stillwater)
Potential depth (ft) of overtopping
along the 28 shoreline systems
< 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
Data Source: BCDC, AECOM
1:77,000
0 0.5 1 Miles
San Leandro
San Lorenzo
San Francisco Bay
Hayward
92
880
Union City
* 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 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
55" Sea Level Rise
Wind Waves during a Storm Event
Potential depth (ft) of overtopping along the 28 shoreline systems
< 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
1:77,000
Data Source: BCDC, AECOM
0 0.5 1 Miles
San Leandro
San Lorenzo
San Francisco Bay
Hayward
92
880
Union City
* 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 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.

Caveats and Assumptions

There are a number of caveats and assumptions to be considered when using and interpreting the analysis and mapping conducted for the ART project. A summary of these is provided below. A more detailed description of the data, methods, caveats, and assumptions is provided in Appendix B.

- The analysis does not account for potential future changes in Bay hydrodynamics or bathymetry, shoreline topography, erosion, subsidence, future construction, levee upgrades, wetland organic matter accumulation, sediment supply, or sediment deposition/resuspension rates.
- Only the location and height of shoreline protection features was considered. Other criteria, including condition, age, maintenance status, potential for future or planned upgrades, or failure outcomes, were not evaluated.
- The height of topographic features (levee, road embankment, etc) was derived from 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 has undergone rigorous quality assurance/quality control, it has not been extensively ground-truthed. Therefore, levee crests or embankment heights may be overrepresented or underrepresented in the DEM used for the inundation mapping.
- The inundation depth and extent for daily high tide was based on the mean higher high water (MHHW) tidal elevation. This approximates future inundation from the highest 'average' daily high tide. Because there are two high and two low tides in San Francisco Bay on any given day the high tide may be more or less than MHHW.
- The inundation depth and extent for the 100-year storm event was based on the extreme tide level with a 1-percent chance of occurring in any given year. Extreme tide levels with greater return intervals (i.e., 500-year event, with a 0.2-percent chance of occurring in a given year) can also occur, and would result in greater inundation depths and extents.
- The depth of inundation was not determined for storm event with wind waves because the physics associated with overland wave propagation and dissipation were not accounted for due to resource limitations. These processes could have a significant effect on the ultimate depth of inundation associated with large coastal wave events.
- The existing 10-year wave heights were used in the analysis. As sea level rises and Bay water depths increase, the potential for larger waves to develop in nearshore areas will increase, potentially resulting in increased inundation and overtopping.
- The inundation maps do not account for changes in rainfall patterns, frequency or intensity, nor do they consider the effect of localized flooding due to rainfall-runoff events or overbank flooding from local tributaries.
- Based on the uncertainty of the topographic data and the modeling results, only areas inundated or overtopped by depths of 0.5 foot or greater were included in the analyses.
- The analysis of overtopping potential does not account for the physics of wave setup and runup, the condition of the shoreline asset, or the potential the asset will fail due to scour, undermining or a breach after the initial overtopping occurs.
- The overtopping potential analysis does not fully capture the potential consequences on inland areas. Short lengths of overtopped shoreline can potentially cause large inland areas to be inundated, and if overtopping causes a structural failure then even larger areas could be inundated with deeper depths.

Summary and Conclusions

The sea level rise analysis and mapping conducted for the ART project was the foundation for understanding exposure of shoreline communities and assets to sea level rise and storm events. The potential overtopping analysis, which built off of the inundation analysis, provided a high level understanding of the likelihood that specific assets will be exposed if a future climate impacts occur, and helps identify specific shoreline vulnerabilities and risks that need to be further evaluated.

Taken together, the analysis and mapping results provide a generalized picture of exposure along the ART project area, and support the more detailed asset-by-asset analysis of exposure that is necessary for the completion of a vulnerability and risk assessment. In the near-term (i.e., mid-century) exposure of the shoreline to sea level rise will be observed first during storm events, and in particular storm events when extreme water levels are combined wind-driven waves, for example, during a winter storm that coincides with an annual high tide such as the king tide, or during an El Nino year. Further evaluation of specific shoreline areas most vulnerable to near-term climate impacts such as 16 inches of sea level rise can be informed by an analysis of overtopping potential such as the one conducted for the ART project.

The majority of the ART project shoreline is adequately protected against 16 inches of sea level rise at high tide. However there are specific locations, representing less than 1% of the total shoreline evaluated (1.2 miles), that will overtop with depths of less then one foot on average. The level of flood protection is greatly reduced if there is a storm event, and even further if there are wind waves during the storm event. For the particular storm event evaluated (i.e., a storm resulting in a 100-year extreme water level) the extent of shoreline exposed and the depth of overtopping increases (21%, or 26 miles, with an average depth of 1 foot); however, with the addition of wind waves 77% of the shoreline (96.7 miles) will overtop with average depths of 3 feet. The widespread and relatively significant depth of inundation of the shoreline system due to overtopping during a storm event with wind waves translates to large inland areas potentially exposed.

With 55 inches of sea level rise, a little more than one third of the shoreline will overtop (36%). However this represents a fairly significant length of shoreline protection (45.7 miles). During a storm event 75% of the shoreline will overtop (96.2 miles), and if there are wind waves nearly the entire shoreline will overtop (96%, 121 miles). On average, there will be 3 feet of overtopping during a storm event (with a range of 1.7 to 4.2 feet). However, this will increase to 5 feet (with a range of 1.9 to 7.3 feet) if there are wind waves. For the worst case observed (system #23, located at the Hayward Regional Shoreline), the average depth of overtopping during a storm event is 3.7 feet, with a maximum depth of 8.8 feet. These depths, which increase with wind waves to an average of 6.8 and a maximum of 11.6 feet, are significant and reflect the potential challenges this portion of the shoreline will face in developing long-term adaptation response strategies.

The results of the overtopping potential analysis do not necessarily correlate to the magnitude of the potential consequences to inland areas from the future climate scenarios evaluated. Not only could shoreline protection systems be improved or enhanced, but they also could be subjected to failure due to repeated exposure to higher tides, stronger currents and increased wave activity. Depending on the location of the overtopping, and if there is a partial or total failure of a shoreline protection asset, the impact on inland areas could be much greater with larger inland areas inundated at greater depths then determined in the current analysis.

The effect of rising sea levels on the shoreline will be observed on a regular basis during the highest of high tides. Further assessments of sea level rise and storm events impacts in the ART project area would benefit from a decision-based approach that uses specific scenarios focused on known thresholds of impact or asset-specific tolerance levels. For example, based on the overtopping potential analysis it may become clear that specific reaches of shoreline are vulnerable to threshold amounts of sea level rise. Using that information, further analysis of the specific tide and storm conditions, and the potential timing and likelihood of those events, would help to prioritize further evaluation of vulnerabilities and development of specific adaptation response solutions.

The analysis and mapping conducted for the ART project used a scenario-based planning approach, with six scenarios focused on two future time frames evaluated. Longer term and more in-depth planning processes that include more detailed and refined studies of particular thresholds of impacts, including specific tide and storm event conditions, will be required to adequately plan for end-of-century climate impacts.

References

Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project. November 2011. Prepared by AECOM and Arcadis for the San Francisco Bay Conservation and Development Commission, Metropolitan Transportation Commission and the California Department of Transportation. Available at http://www.mtc.ca.gov/news/current_topics/10-11/sea_level_rise.htm.

Marcy, Douglas, William Brooks, Kyle Draganov, Brian Hadley, Chris Haynes, Nate Herold, John McCombs, Matt Pendleton, Sean Ryan, Keil Schmid, Mike Sutherland, and Kirk Waters. 2011. "New Mapping Tool and Techniques for Visualizing Sea Level Rise and Coastal Flooding Impacts." In *Proceedings of the 2011 Solutions to Coastal Disasters Conference, Anchorage, Alaska, June 26 to June 29, 2011*, edited by Louise A. Wallendorf, Chris Jones, Lesley Ewing, and Bob Battalio, 474–90. Reston, VA: American Society of Civil Engineers.

The Nature Conservancy and NOAA National Ocean Service Coastal Services Center, 2011, Marshes on the move: A manager's guide to understanding and using model results depicting potential impacts of sea level rise on coastal wetlands. Available at: www.csc.noaa.gov/publications/Marshes_on_the_move.pdf

National Oceanic and Atmospheric Administration Coastal Services Center. August 2009. Coastal Inundation Mapping Guidebook. Available online at:

Chapter 3. Vulnerability and Risk Classification

A vulnerability and risk classification system was developed to assist with the transition to adaptation. The purpose was to sort and characterize vulnerabilities and risks to make it easier to develop a robust adaptation response. The classification step also provided an opportunity to test the effectiveness of a unique approach for organizing and communicating the results of a vulnerability and risk assessment, and identifying key issues across diverse categories of assets.

Finding the Right Approach for the ART Project

The ART project staff designed the classification system in order to identify key issues and planning priorities in a way that would be replicable, straightforward to implement, and transparent to all, not just those directly involved in the project. Research on adaptation planning processes, examples from other planning efforts, and previous experience with prioritizing vulnerabilities informed the decision to use a classification rather than a numeric prioritization, ranking or rating approach. (Bintliff 2011).

Many adaptation planning processes prioritize vulnerability and risk numerically. The vulnerability and risk assessment of transportation projects conducted as part of the ART project is an example of this approach. The project consultants tested the use of ranking vulnerabilities, and developing integrated risk “scores” as a means to compare and prioritize different types of ground transportation assets (AECOM 2011). Scores were based on the average of numerical ratings assigned to different consequence criteria such as cost to rebuild the asset, economic impact of loss of the asset, and public safety issues due to impacts to the asset.

In practice, this approach provided a replicable method for factoring quantitative information, such as replacement costs and use levels, into prioritizations. However, it also presented some challenges. The criteria proved difficult for stakeholders to use when asked to score assets they did not own or operate, or of which they had little direct knowledge. In addition, some of the criteria were poorly suited for scoring certain types of ground transportation assets included in the project, such as the Bay Trail, and resulted in under-estimating the consequences of impacts to these assets. In order to balance vulnerability and risk scores, consequences to the region if the asset were to be lost were also considered. The consequence information came from stakeholder input and provided additional context about the significance of some assets. The project consultants conveyed this additional consequence information in risk profile sheets that were prepared for a subset of the transportation assets.

Examples from other planning efforts have also shown that numerical ratings can be misleading. Scores are generally assigned based on best professional judgment rather than a quantitative analysis. However, the use of a numerical score can suggest that a quantitative analysis was undertaken or that there is a level of certainty that does not exist. Furthermore, averaging across different scoring criteria to obtain a single value can over-simplify the overall risk, and potentially underestimate severe consequences (Bintliff 2011). This may result in an asset being removed from further consideration in a study. A weighting system for different scoring criteria could address this issue, but it also makes the ranking process more complex and more difficult to interpret. It can be difficult to determine how risks and vulnerabilities were prioritized when the numerical score is taken forward without the appropriate context. Regardless of the scoring method, precise definitions of the assumptions used in the scoring system must be presented and communicated to ensure transparency, replicability, and clarity (Bintliff 2011).

For an adaptation planning project focused on one asset type with access to sufficient data for quantitative analysis, scoring can be helpful, especially to managers who are prioritizing issues for assets that they themselves manage. However, applying this method in the ART project across multiple asset categories, jurisdictions, and management boundaries would be complex and time-consuming, and ultimately unlikely to advance the development of adaptation strategies. For example, attempting to numerically rank and compare the Bay Bridge, the Oakland International Airport, the Emeryville Crescent, and the Bay Trail would not likely lead to useful outcomes.

Instead of a numerical scoring or ranking system, the ART project developed an approach to classify vulnerabilities and risks into actionable categories that would help asset managers and decision-makers understand the defining characteristics of an issue (e.g., its timing, scale, responsibility for management, etc.). This approach better supports informed discussions and decisions– both internal to the agencies participating in the ART project and in coordination with other interested parties and stakeholders – about priorities and potential adaptation strategies. Additionally, defining key issues and planning priorities in terms of actions to be taken rather than numerical risk rankings makes the results of the assessment clearer and more useful to decision-makers and asset managers.

The Classification Approach

Classifying the vulnerabilities and risks provided a way to organize and communicate the results of the ART assessment and helped project participants and other stakeholders prioritize issues, identify potential adaptation strategies and their tradeoffs, and recognize opportunities for new or improved coordination.

For each of the asset categories, information about sea level rise exposure, sensitivity, adaptive capacity, and consequences was summarized into brief issue statements. The issues were classified according to specific characteristics of vulnerability and risk. Staff and working group members chose characteristics that they felt would best help prioritize issues and weigh adaptation responses.

Vulnerabilities were evaluated according to four classifications: *timing*, *management control*, *physical and functional qualities*, and *information*. Four additional classifications, *scale, people, ecosystem services,* and *economy*, were used to identify key dimensions of risk that should be considered in prioritizing issues.

Timing is an approximation of the onset of vulnerability: "near-term," "mid-century," or "end of century" describes when impacts are likely to be felt. The timing of vulnerabilities is potentially relevant to prioritizing issues and deciding how to sequence and coordinate adaptation strategies. All else being equal, issues that are likely to develop sooner should be prioritized. For example, managers deciding how to allocate limited funding for redesign of playing fields at multiple parks might choose to apply the funds to the playing fields that first become vulnerable to impacts. Similarly, awareness of differences in timing of impacts to contaminated sites would be helpful in setting priorities for remediation efforts.

The timing of vulnerabilities should not be used as a proxy for the importance of issues, or as a deadline for when to begin planning or taking action. Indeed, most of the issues identified in the ART assessment require significant lead-time for planning and implementation of strategies to reduce vulnerability and risk.

Most often the timing of a vulnerability will coincide with exposure of the asset (or system of assets) to one of sea level rise projections addressed in the ART assessment, but this is not always the case. For example, a shoreline feature (e.g., trail, wetland, etc.) might not be vulnerable to impacts until end-of-century despite being exposed to mid-century sea level rise, because it is resilient to impacts. In contrast, vulnerabilities may develop prior to exposure (e.g., in the near-term or mid-term) because of existing stressors on an asset, and/or interdependencies with other assets that are exposed to impacts earlier.

Management control describes challenging management characteristics of an asset. For example, the management or regulatory structure of some assets may result in the need for a long lead-time to develop and implement adaptation responses. This classification can also help agencies pinpoint challenges and opportunities within and outside their organizations for addressing certain vulnerabilities and risks. Management control factors that were considered include:

- **Multi-agency effort:** Many issues cannot be resolved with a single-agency effort because multiple agencies have relevant responsibilities and authorities. These situations often indicate the need for an early start to planning to allow enough time for inter-agency coordination.
- **Inadequate management approaches:** The ways in which agencies currently approach some issues may no longer be adequate to address new challenges that sea level rise impacts will introduce. For example, the planning horizons commonly used for activities such as capital improvement plans and general plan updates may need to be extended to take into account future sea level rise impacts. Another example could occur in a park where it becomes impossible to prevent flooding and managers must consider novel management practices to accommodate flooding and minimize consequences.
- **Inadequate authority or regulatory mechanisms:** Existing management authority or regulatory mechanisms may be too limited or inadequate to address certain issues. For example, agencies that regulate contaminated sites are limited in their ability to set and implement cleanup priorities because the majority of these sites are privately owned and cleanup depends on voluntary efforts. If property owners are unwilling to clean up such sites, additional time and effort are necessary to compel cleanup and extract or find funding. It is possible that none of the responsible agencies have the authority or mandate to address key aspects of vulnerability and risk presented by sea level rise.

  Managers may also face situations in which implementation of existing policies and regulations will exacerbate vulnerability to or consequences of sea level rise and storm event impacts.
- **Financing:** Sea level rise will introduce novel management challenges, and managers will encounter situations where there are no sources of money to apply towards addressing certain issues. Other financing challenges include restrictions on the use of available funds and the inability to access new funding sources that could be applied to resolve an issue. It is important to distinguish these challenges related to access to applicable funding sources from fiscal limitations on planning, operating or management budgets. Most agencies do and will continue to deal with budget limitations. Financing challenges associated with sea level rise vulnerabilities and risks may require seeking out new sources of funding outside of traditional budget allocations, and/or allowances for re-allocating funding.

Physical and functional qualities identifies a subset of existing conditions or design and functional aspects of an asset that make it acutely sensitive or severely limit its adaptive capacity to sea level rise and storm impacts. Factors that were considered include:

- **At or below grade:** Infrastructure such as roads, trails, living space in homes, or pump stations that are built at or below grade are more likely to be susceptible to flooding due to their low elevation.
- **Water sensitivity:** Exposure to water due to flooding or groundwater rise is especially damaging or harmful for certain types of assets. For example, electrical or mechanical components of utility systems might not be able to continue functioning if they get wet, resulting in loss of services (e.g., power, water treatment). Additionally, in areas with contamination, exposure to flooding and rising groundwater could result in water soluble contaminants going into solution and spreading.
- **Sensitivity to salinity:** Sensitivity to salinity is another factor that increases vulnerability to sea level rise impacts. Assets that are sensitive to salinity include grass and other landscape features, as well as corrodible materials used in utilities infrastructure and storage tanks.
- **Highly erodible:** Some assets are especially sensitive to impacts because they are highly erodible. Beaches, marshes, mudflats and levees (including trails built on levees) are obvious examples. Erosion is also a sensitivity factor for contaminated lands where sediment-bound contaminants could be spread, and for buried pipelines that could be uncovered due to erosion and thereby exposed to potential damage.
- **Increased liquefaction potential:** Seismic susceptibility of infrastructure is a significant concern throughout the Bay Area. Higher groundwater and longer-lasting flooding could increase the liquefaction potential of certain areas (permanently or temporarily), leading to a greater risk of damage to infrastructure during an earthquake.
- **Wetlands sensitivities:** For wetlands, an insufficient supply of sediment and limited space for accommodating inland shift of wetlands habitat are physical qualities that increase sensitivity to impacts.
- **Time-sensitivity:** Certain infrastructure in the subregion serves time-sensitive functions that cannot tolerate even short disruptions. For example, the seaport transports fresh agricultural products that would spoil if flooding caused delays or closures.
- **Lack of system redundancy:** For some types of assets, such as the seaport and airport, there is a fundamental, system-wide lack of redundancy or alternatives for serving comparable functions. Some vulnerable assets lack redundancy because suitable alternatives are also vulnerable to impacts.
- **Dependence on vulnerable assets:** The functionality of some assets is dependent on other, vulnerable assets or systems. For example, some of the main access roads to Oakland International Airport are vulnerable to impacts before the airport itself. Therefore, while the airport may not be exposed, its function may be severely constrained if passengers and goods cannot get to and from the airport.
- **Fixed, linear systems:** The rail system used for cargo and passenger transportation is especially sensitive to impacts because it relies on fixed, linear infrastructure. Depending on the location, damage at a single point along one rail line can potentially disrupt service throughout the rail network until the damage is repaired.

Information identifies challenges in obtaining the information necessary to sufficiently understand sea level rise vulnerability and risk. In preparing the ART assessment, project staff determined that these challenges were not only barriers to fully understanding the issues, but were themselves causes of vulnerability and risk. Easy access to relevant, up-to-date, and appropriate information bolsters managers' capacity to successfully address the issues identified in the ART assessment. Types of information challenges that were identified included:

- **Lack of information:** For some assets, necessary information – such as elevation data or precise locations of hazardous materials – has not been collected or compiled, or is so outdated as to no longer be relevant.
- **Unavailable information:** In other cases, relevant information exists, but is not available to managers because, for example, it is held privately, or the cost of acquiring or analyzing it is prohibitive.
- **Poorly coordinated information sources:** Another common information challenge encountered during the ART assessment was that necessary information is collected or held by multiple sources that are poorly coordinated. Inconsistencies in collection methods or reporting norms (e.g., naming systems) can make it virtually impossible to compile the various data, or even cross-reference overlapping data sources.

Scale describes the geographic level(s) at which the consequences of a climate impact will be felt. In combination with other classifications, scale can help managers identify issues with serious consequences that need to be prioritized; identify possible adaptation strategies by considering the whole system; and identify other managers and stakeholders that may need to be involved in developing an adaptation response. Scales considered range from the site or asset itself (e.g., loss of homes) to the nationwide consequences of sea level rise and storm event impacts (e.g., disruptions in service at Oakland International Airport).

People broadly categorizes how the consequences of an issue affect people where they live, work, access key services such as health care, and conduct other necessary day-to-day activities. Combined with the other classifications, this underscores high consequence issues that managers and decision-makers should prioritize. Factors considered were impacts to:

- **Health and safety:** Damage and disruptions to emergency response centers such as fire and police stations, emergency shelters, and health-care facilities could prevent effective response and recovery from sea level rise and storm event impacts.
- **People where they live:** This includes damage to homes and entire neighborhoods as well as disruptions to key services that residential areas rely on, such as utilities.
- **People's livelihoods:** Impacts on employment centers as well as employees' access to jobs via roads, the Bay Trail, and transit were identified.
- **Socially vulnerable populations:** The ART assessment identified populations such as renters, non-English speakers, persons with health or physical mobility constraints, and others who face greater barriers to planning for and responding to impacts.
- **People where they recreate:** The assessment identified consequences to public spaces, such as parks and the Bay Trail, that provide highly valued recreation opportunities.

Ecosystem Services identifies consequences on the services provided by a natural shoreline feature (e.g., wetland). Types of services that were considered include biodiversity, flood and erosion control, water quality improvement, and carbon sequestration. For example, loss of a wetland that acts as a buffer between the Bay and inland areas could diminish the protection that it provides against flooding and erosion in adjacent neighborhoods. These consequences may also result from secondary effects due to impacts on other asset types (e.g., a wastewater treatment system), which in turn harm the capacity of a natural shoreline to provide ecosystem services.

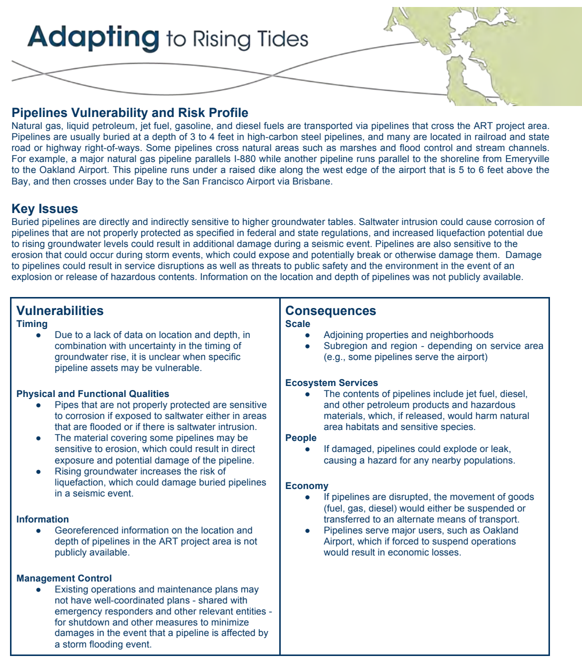
Economy identifies consequences on important drivers of economic health in the region and subregion. These include impacts to goods movement, commuting, employment centers, and business sectors.

Outcomes of the Classification Step

Applying the classification system generated products and outcomes that support adaptation planning.

Asset Category Profiles: Classifications for each asset category (i.e. community land use, facilities and services; ground transportation; airport; parks and recreation; etc.) have been summarized into profiles (Figure 1) that detail the important and common characteristics of vulnerability and risk for that category. These asset category profiles helped define key issues from the assessment. The profiles also enabled ART project staff and the working group to identify a pool of strategies for each category that could be applied to reduce exposure and sensitivity or, conversely, increase adaptive capacity for assets within that category.

Figure 1. Example of a profile sheet for an asset category


Adapting to Rising Tides

Pipelines Vulnerability and Risk Profile
Natural gas, liquid petroleum, jet fuel, gasoline, and diesel fuels are transported via pipelines that cross the ART project area. Pipelines are usually buried at a depth of 3 to 4 feet in high-carbon steel pipelines, and many are located in railroad and state road or highway right-of-ways. Some pipelines cross natural areas such as marshes and flood control and stream channels. For example, a major natural gas pipeline parallels I-880 while another pipeline runs parallel to the shoreline from Emeryville to the Oakland Airport. This pipeline runs under a raised dike along the west edge of the airport that is 5 to 6 feet above the Bay, and then crosses under Bay to the San Francisco Airport via Brisbane.

Key Issues
Buried pipelines are directly and indirectly sensitive to higher groundwater tables. Saltwater intrusion could cause corrosion of pipelines that are not properly protected as specified in federal and state regulations, and increased liquefaction potential due to rising groundwater levels could result in additional damage during a seismic event. Pipelines are also sensitive to the erosion that could occur during storm events, which could expose and potentially break or otherwise damage them. Damage to pipelines could result in service disruptions as well as threats to public safety and the environment in the event of an explosion or release of hazardous contents. Information on the location and depth of pipelines was not publicly available.

Vulnerabilities

Timing
- Due to a lack of data on location and depth, in combination with uncertainty in the timing of groundwater rise, it is unclear when specific pipeline assets may be vulnerable.

Physical and Functional Qualities
- Pipes that are not properly protected are sensitive to corrosion if exposed to saltwater either in areas that are flooded or if there is saltwater intrusion.
- The material covering some pipelines may be sensitive to erosion, which could result in direct exposure and potential damage of the pipeline.
- Rising groundwater increases the risk of liquefaction, which could damage buried pipelines in a seismic event.

Information
- Georeferenced information on the location and depth of pipelines in the ART project area is not publicly available.

Management Control
- Existing operations and maintenance plans may not have well-coordinated plans - shared with emergency responders and other relevant entities - for shutdown and other measures to minimize damages in the event that a pipeline is affected by a storm flooding event.

Consequences

Scale
- Adjoining properties and neighborhoods
- Subregion and region - depending on service area (e.g., some pipelines serve the airport)

Ecosystem Services
- The contents of pipelines include jet fuel, diesel, and other petroleum products and hazardous materials, which, if released, would harm natural area habitats and sensitive species.

People
- If damaged, pipelines could explode or leak, causing a hazard for any nearby populations.

Economy
- If pipelines are disrupted, the movement of goods (fuel, gas, diesel) would either be suspended or transferred to an alternate means of transport.
- Pipelines serve major users, such as Oakland Airport, which if forced to suspend operations would result in economic losses.

To prioritize issues, evaluate strategies, understand implementation challenges and opportunities, and recognize coordination needs, planners and managers also need to take a detailed look at the vulnerabilities and risks to their specific assets of concern, (e.g. a neighborhood, a pipeline, an airport runway, a park, a wastewater treatment facility, etc). A valuable function of the category profiles has been to make this task much simpler. Rather than start from scratch with this analysis, an asset manager can use the category profiles as a starting point for identifying aspects of vulnerability and risk that may need to be addressed. The category profile also provides a backstop by calling out aspects that might easily be missed if a manager relied only on an asset-specific analysis. The pool of adaptation strategies – developed with the use of the category profiles – serves as a resource for building a response for the specific asset(s).

In testing the classification system for a specific asset or subset of assets, project staff and the working group identified mismatches. Mismatches are discrepancies or conflicts among characteristics of an issue that could hinder or delay development and implementation of adaptation strategies. For example, impacts on the roads that provide access to Oakland International Airport will have far-reaching consequences for airport operations, important utilities, ground transportation, and land use, services, and facilities near the airport. A large-scale, coordinated, multi-agency response will be needed to address these issues. However, the anticipated near-term occurrence of the impacts means that there is relatively little time to implement such a complex planning and response effort. Along with the other classifications, recognizing these mismatches can help managers identify planning priorities and narrow in on appropriate adaptation strategies for specific assets.

Key, Cross-Cutting Issues: In addition to producing the profiles, conducting the classification step expanded the understanding of key issues identified in the vulnerability and risk assessment.[1] The consequence classifications – scale, people, environment and economy – called out key issues that have severe or widespread negative social, environmental and/or economic consequences. For example, severe consequences to public health and the environment and the local economy will result from partial or complete failure of a wastewater treatment plant even for relatively short time periods.

Details about the relationships among issues such as inter/dependencies among assets, and vulnerabilities and consequences that "cascade" from one asset or geographic area to another were also revealed. For example, the rail line which is essential for both cargo and passenger transportation is highly vulnerable within the subregion, but it is also vulnerable in northern Contra Costa County. Disruptions to the electrical utilities create a cascade of issues in other asset categories such as community land use, facilities and services; ground transportation and more. Some of the main access roads to Oakland International Airport are vulnerable to impacts long before the airport itself.

Additionally, certain issues emerged that have severe and/or widespread consequences and highly complex, intertwined vulnerabilities. These key, cross-cutting issues require holistic adaptation planning because actions to address vulnerabilities of an individual asset strongly affect other assets' vulnerability to sea level rise, and potentially limit the range of adaptation options available to managers of other assets. To test a method for informing and initiating this type of adaptation planning, project staff used the classification system to identify and further assess geographic areas, or "focus areas," within the subregion that have key, cross-cutting issues that must be addressed together. This focus area approach involves considering a suite of issues across multiple asset categories and jurisdictions in identifying and evaluating adaptation strategies and implementation options. The goal of this approach is to develop robust adaptation responses that increase resilience across different types of assets and geographic boundaries.

References

Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project. November 2011. Prepared by AECOM and Arcadis for the San Francisco Bay Conservation and Development Commission, Metropolitan Transportation Commission and the California Department of Transportation. Available at http://www.mtc.ca.gov/news/current_topics/10-11/sea_level_rise.htm

Assessing Climate Change Vulnerability & Risk. December, 2011. Prepared by Jacob Bintliff, BCDC Planning Intern, UC Berkeley College of Environmental Design, Department of City & Regional Planning. Available at: http://www.adaptingtorisingtides.org/project-reports/

[1] Key issues and cross-cutting issues are summarized in the Vulnerability and Risk Synthesis.

Chapter 5. Community Land Use

Community land use describes the services and facilities, such as job centers, residences, schools, and hospitals, that together make up neighborhoods and reflect and support the way that people live. The ART project assessment of community land use considers the vulnerability and risk of people - where they live and work - the property they may own or rely on, and the key services and facilities that support and maintain the social and economic interactions that tie communities together.

Understanding the vulnerability and risk of a broad and varied asset category such as community land use to climate change impacts is both necessary and challenging. It is critical to the process of developing adaptation strategies for the residents, properties, employees, facilities, and services of a region. Developing robust, multi-objective adaptation approaches that address cross-sectoral and cross-jurisdictional issues are necessary to truly build community resilience.

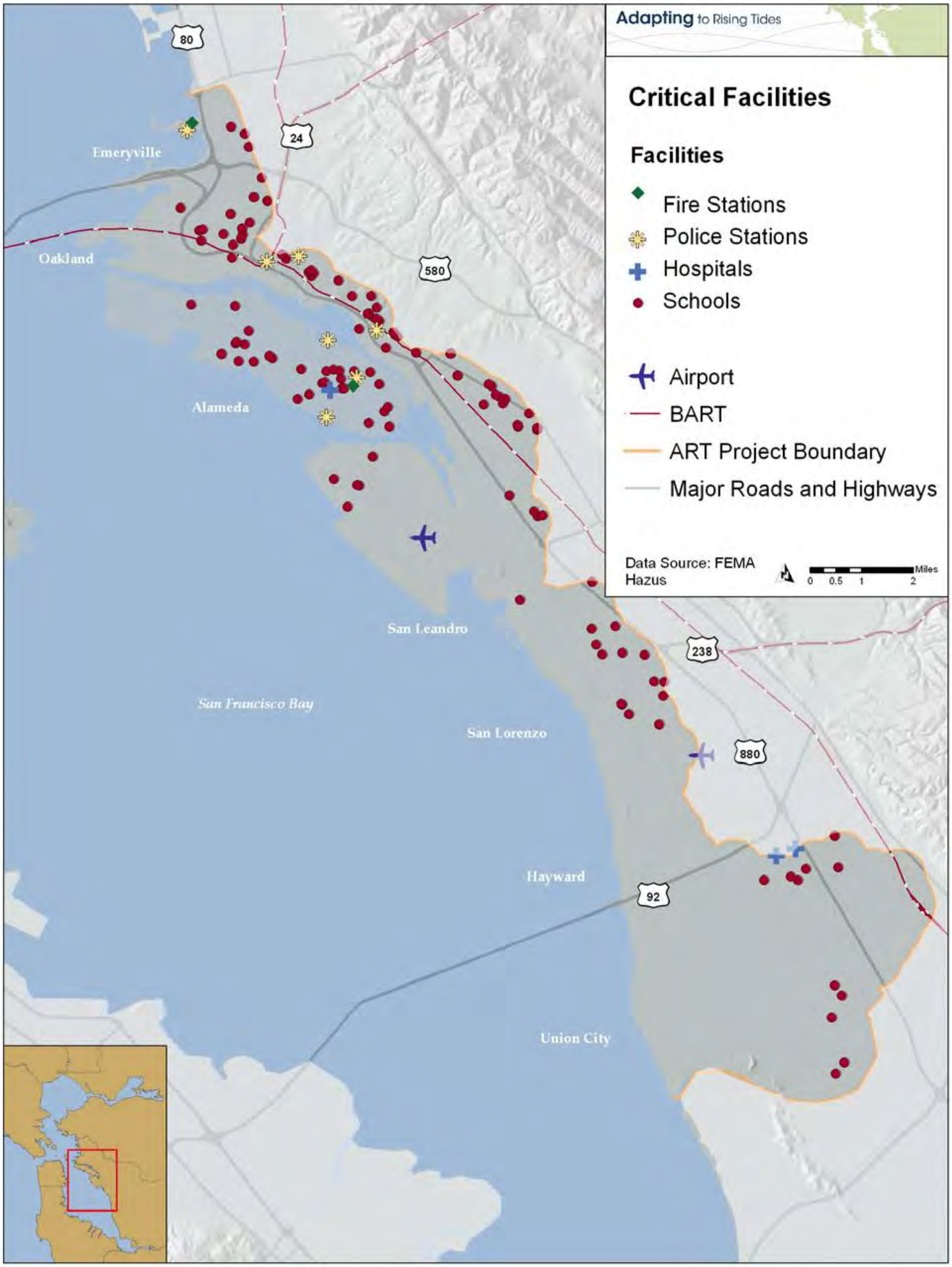
Careful consideration must be given when analyzing the vulnerability and risk to community land use assets. The consequences of sea level rise for individual residents, neighborhoods, and communities as a whole, and even the region can be significant and far-reaching. While the resilience of all types of community land uses is important, particular consideration must be given to residential uses. Unlike office buildings or industrial sites, it can be exceedingly difficult to either relocate or reconstruct the complex social network and individual ties that can develop in a residential neighborhood. The proximity of families to schools, access to known and reliable services and facilities, and the close personal relationships often forged between and among neighbors are features of neighborhoods that cannot easily be recreated, and once lost are not easily rebuilt.

The assessment described in this report, and the findings discussed in this chapter and others, will be used to develop strategies to address community vulnerability and risk to sea level rise and storm events in the ART project area. Developing successful adaptation strategies for community land use will depend on a firm understanding of how sensitive communities are to potential sea level rise and storm events; the inherent adaptive capacity of the land uses, facilities, and services the community relies on; and the potential consequences to a neighborhood, community, and even the region, if an impact were to occur. Therefore, this community land use assessment includes an evaluation of exposure, sensitivity, adaptive capacity, and consequences (see Introduction for definitions) for the following:

- Residents
- Employees
- Property values
- Community facilities and services

Four categories of community facilities and services are considered. These include the facilities responsible for **emergency and disaster response,** such as hospitals, police and fire stations, and shelter-in-place locations (schools and churches); facilities that provide **services to at-risk populations,** such as health clinics, homeless shelters, and food banks; facilities with **vulnerable, less mobile populations,** such as senior housing, jails, long-term care facilities, and childcare centers; and **animal facilities,** such as shelters. Other facilities and services critical to communities, such as park and recreation areas, water and energy utilities, and ground transportation, are considered in other sections of this report. Figure 1 shows a selection of these facilities and services in the ART project area.

Figure 1. Map of selected community facilities and services in the ART project area.



The community land use exposure analysis for the ART project was conducted in collaboration with the Pacific Institute[1]. Pacific Institute staff completed a technical analysis and provided a report on the exposure to sea level rise and storm events of the residents, employees, property values, and community services and facilities in the ART project area. A summary of the Pacific Institute's exposure findings is provided below, and the complete report, which includes an analysis of population and household demographics as well as social vulnerability in the ART project area, is provided in Appendix D.

Following the exposure analysis is a discussion of the sensitivity and adaptive capacity of the community land uses found in the ART project area. Taken together, exposure, sensitivity and adaptive capacity informs an understanding of vulnerability - the degree of susceptibility, or inability to accommodate adverse impacts of climate change (see Introduction for a detailed description of vulnerability). Each of these components is critical to understanding vulnerability. For example, a community facility that is exposed to storm event impacts, such as flooding, may not be vulnerable if it is not physically damaged and/or can continue to maintain its primary function. On the other hand, homes exposed to the same flood that are damaged and no longer livable without rehabilitation are themselves vulnerable, and can cause the neighborhood and community where they are located to be vulnerable.

Developing adaptation response strategies that address identified vulnerabilities requires consideration of the magnitude of the consequences, if a sea level rise impact were to occur. Community land use, as defined here, is a very broad and varied asset category. A generalized, high level discussion of the consequences of sea level rise and storm event impacts on community land use in the ART project area is provided. A more detailed and specific analysis of the consequences on such a critical asset category such as community land use is warranted; however, the ART project's multi-sector/multi-jurisdiction adaptation planning approach makes this level of analysis especially challenging. Further evaluation of consequences for the individual cities or regional entities responsible for managing community land use assets in the project area would be beneficial, and can be guided by the information presented herein.

Exposure

Exposure is the extent to which an asset experiences a specific climate impact such as storm event flooding, tidal inundation, or elevated groundwater. The exposure of residents, employees, property value, and community facilities and services in the ART project area was evaluated for two sea level rise projections and three Bay water levels. The two sea level rise projections, 16 inches (40 cm) and 55 inches (140 cm), correlate approximately to mid- and end-of-century. These projections were coupled with three Bay water levels: the highest average daily high tide represented by mean higher high water (MHHW), hereafter "high tide" or "daily high tide;" the 100-year extreme water level, also known as the 100-year stillwater elevation (100-year SWEL), hereafter "100-year storm" or "storm event;" and the 100-year extreme water level coupled with wind-driven waves, hereafter "storm event with wind waves" or "wind waves." These water levels were selected because they represent a reasonable range of potential Bay conditions that will affect flooding and inundation along the shoreline. For more information about sea level rise projections and Bay water levels evaluated see Chapters 1 and 2.

The data sources, methods, and results of the exposure analysis are summarized below. For information on the ART project exposure analysis see Appendix C, for the data and methods used by the Pacific Institute see Appendix D.

[1] The Pacific Institute (www.pacinst.org) is a tax-exempt 501(c)(3) organization established in 1987 with offices located in the City of Oakland.

Exposure in the ART Project Area

Residents

The presence of residential housing units within areas potentially exposed to tidal inundation, storm event flooding and rising groundwater levels is of particular concern. Past experience with coastal flooding hazards, such as significant winter storms, hurricanes and tsunamis has demonstrated that residential neighborhoods are not only extremely vulnerable to these events, but also tend to be the slowest to recover and have the greatest difficulty in doing so.

The ART project analysis is based on an estimation of the residential population exposed to the two sea level rise projections and three Bay water levels. This analysis estimates the number of residents that could potentially experience a climate impact such as tidal inundation or storm event flooding. Careful consideration must be given to both the analysis and interpretation of residential exposure, as fully understanding the impact of inundation or flooding cannot be achieved without understanding the other components of vulnerability and risk (i.e., sensitivity, adaptive capacity, and consequences, each of which is discussed later in this section).

In the year 2000, there were more than 786,874 residents in the ART project area, representing more than half of Alameda County's total population of 1,443,741. US Census data at the census block level from the year 2000[2] was used to estimate the exposure of residents in the ART project area to sea level rise and storm events. The percentage area of all census blocks exposed was calculated, and then the population within the exposed area was estimated and summed.

The number of residents that would be exposed to flooding in the ART project area ranges from 2,000 with 16 inches of sea level rise at high tide, to 123,000[3] with 55 inches of sea level rise during a storm event with wind waves. Further analysis was conducted on the demographics of residents and households potentially exposed with a focus on characteristics that increase vulnerability. A description of the methods used and the results of this analysis can be found in the Pacific Institute report (see Appendix D), and an interpretation of this analysis is presented in a white paper on equity and sea level rise completed for the ART project[4].

Employees

Sea level rise and storm events disrupt not only the lives of residents, but also the lives of the people whose jobs are in exposed areas and the economic health of both individuals and the region. As of June 2011, the ART project area provided employment to a total of nearly 310,000 people. The exposure analysis of employees in the ART project area was conducted by California Employment Development Department, Labor Market Information Division, Statewide Information Services Group (EDD-LMID), using data on business establishments[5] from the Quarterly Census of Employment and Wages from June 2011. Because this data was not publicly available, ART project staff provided EDD-LMID staff with exposure data for the ART project area, and EDD-LMID staff produced aggregate exposure calculations for employees in each city. An analysis of the storm event with wind waves scenarios was not conducted. The exposure of employees in the ART project area ranges from approximately 1,000

---

[2] 2000 Census was used because the population data from the 2010 Census was aggregated based on new geographic boundaries that are not compatible with the 2000 Census.

[3] These figures reflect year 2000 population rather than projected for mid- and end-of-century populations. The population exposed is therefore an estimate, and will differ based on future conditions, including population growth in the ART project area.

[4] Addressing Social Vulnerability and Equity in Climate Change Adaptation Planning. June 2012. Available at http://www.adaptingtorisingtides.org/equity/.

[5] The terms "business establishment" and "employer" are sometimes used interchangeably. However, an employer can have multiple geographic locations (e.g., a restaurant chain), while a business establishment is a single, particular location.

employees exposed to the daily high tide with 16 inches of sea level rise, to over 68,500 employees exposed to storm event flooding with 55 inches of sea level rise (see Table 1).

Property Value

Two evaluations were conducted for property in the ART project area: the *replacement costs of buildings and their contents* were evaluated using FEMA's HAZUS model, and the *value of land and improvements* was evaluated using data from the Assessor's Office. The HAZUS model uses a database that contains the value of buildings and their contents based on information from a number of sources. Values are provided for residential, commercial, industrial, agricultural, religious, governmental, and educational land uses in each census block. HAZUS uses a statistical model to estimate rebuilding or replacement costs based on square footage, number of stories, building material, and other variables. The Alameda County Assessor's Office provided data on the value of land and improvements such as buildings. This data included a parcel boundary GIS file and the property database, which contained information about land and property values. The county maintains this information for the purpose of levying taxes.

According to FEMA's HAZUS model, the total replacement cost of buildings and their contents in the ART project area is roughly $45 billion. The Alameda County Assessor's Office estimates property value at nearly $87 billion dollars. An exposure analysis was conducted for replacement costs as well as assessed property values to estimate, from two different perspectives, the monetary value that may be exposed to damage or loss due to sea level rise.

Based on the HAZUS model, the replacement costs of buildings and contents in the ART project area ranges from $323 million exposed to the daily high tide with 16 inches of sea level rise, to $10.7 billion exposed to a storm event and wind waves with 55 inches of sea level rise ($7.2 billion exposed to storm events and $3.5 billion exposed to wind waves only). Based on the Assessor's data, the value of property exposed to sea level rise ranges from $694 million exposed to the daily high tide with 16 inches of sea level rise, to $19.6 billion ($15.1 billion exposed to storm events and $4.5 billion exposed to wind waves only) exposed to a storm event and wind waves with 55 inches of sea level rise (see Table 1).

Table 1. Residents, Employees, and Property Values (in millions of dollars) exposed to 16 and 55 inches of sea level rise in the ART project area.

		16" SLR			55" SLR		
		Daily High Tide	Storm Event		Daily High Tide	Storm Event	
	Total	Exposed	Exposed	Exposed to wind waves only	Exposed	Exposed	Exposed to wind waves only
Residents	786,874						
Number		1,952	17,321	62,313	38,266	80,063	43,724
Percent		0%	2%	8%	5%	10%	6%
Employees	309,634						
Number		1,011	9,265	--	22,722	68,513	--
Percent		0%	3%	--	7%	22%	--
Replacement Costs ($M) (HAZUS)	45,126						
Replacement costs		323	1,633	5,591	3,139	7,236	3,485
Percent		1%	4%	12%	7%	16%	8%
Assessed value ($M)	86,591						
Assessed value		694	4,117	11,015	7,875	15,122	4,483
Percent		1%	5%	13%	9%	17%	5%

Community Facilities and Services

The ART project analyzed the exposure of four categories of community facilities and services: emergency and disaster response; facilities and services for at-risk populations; facilities housing vulnerable, less mobile populations; and animal facilities. The exposure analysis of these facilities and services (Table 2) was conducted using publicly available data from the following sources: California Community Care Licensing Division, FEMA HAZUS, Association of Bay Area Governments (ABAG), and the California Department of Public Health. Some sites – such as jails – were located through focused Internet searches rather than in a publicly available database. One of the terms, "health care facility," refers to many types of facilities, ranging from community health clinics to dialysis centers to administrative buildings for hospice care. Some locations appear more than once across the databases. For example, the same facility could provide senior housing and long term care, or the same property could house a daycare center or preschool – labeled as "childcare center" – and a K-12 school. These facilities serve different functions and populations, presenting different concerns in the event of flooding. For example, evacuating bed-ridden patients receiving long-term care poses a different evacuation challenge than evacuating healthy seniors. Therefore, such facilities are included in both categories under which they are listed, with a note indicating where overlap occurs in the *Exposure by City* section. Some facilities, such as schools, also serve as shelters during emergencies.

There are 37 emergency response facilities in the ART project area: ten hospitals, six police stations, and 21 fire stations. With 16 inches of sea level rise, none of these facilities are exposed to the daily high tide, but three fire stations are exposed to storm event flooding and an additional four facilities – also fire stations – are exposed to wind waves only. With 55 inches of sea level rise, four fire stations are exposed to the daily high tide. An additional three fire stations and one police station are exposed to storm events, and one additional fire station is exposed to wind waves only.

Just over 200 facilities in the ART project area serve at-risk populations. Two thirds of these are health care facilities, with the remainder comprised of homeless shelters, group homes, food banks, and jails. None of these facilities are exposed to the daily high tide with 16 inches of sea level rise, and only one – a health care facility – is exposed to storm events. Eleven additional health care facilities, two homeless shelters, and two food banks are exposed to wind waves only. With 55 inches of sea level rise, four health care facilities are exposed to the daily high tide. Fourteen facilities are exposed to storm events, and an additional seven are exposed to wind waves only.

Over 600 facilities in the ART project area serve vulnerable, less mobile populations. There are 159 senior housing facilities, 52 long-term care facilities, 253 childcare centers, and 172 schools (some of these locations provide multiple services; cross-listings are discussed in the Exposure by City section). With 16 inches of sea level rise, no facilities serving vulnerable, less mobile populations are exposed to the daily high tide. Seventeen are exposed to storm events, and 71 are exposed to wind waves only. With 55 inches of sea level rise, 38 facilities are exposed to the daily high tide, 87 are exposed to storm event flooding, and 35 are exposed to wind waves only.

There is one animal facility in the ART project area. This facility, an animal shelter in the City of Alameda, is exposed to all of the future climate scenarios evaluated, except for the daily high tide with 16 inches of sea level rise.

Table 2. Number of community facilities and services exposed to 16 and 55 inches of sea level rise in the ART project area.

		16" SLR			55" SLR		
		Daily High Tide	Storm Event		Daily High Tide	Storm Event	
Type of facility	Total	Exposed	Exposed	Exposed to wind waves only	Exposed	Exposed	Exposed to wind waves only
Emergency response	**37**	**0**	**3**	**4**	**4**	**8**	**1**
Hospitals	10	0	0	0	0	0	0
Police stations	6	0	0	0	0	1	0
Fire stations	21	0	3	4	4	7	1
Serving at-risk populations	**218**	**0**	**1**	**15**	**4**	**13**	**7**
Health care facilities	144	0	1	11	4	9	5
Homeless shelters	14	0	0	2	0	2	0
Group homes	26	0	0	0	0	0	0
Food banks	30	0	0	2	0	2	2
Jails	4	0	0	0	0	0	0
Serving vulnerable, less mobile populations	**658**	**0**	**17**	**71**	**38**	**87**	**35**
Senior housing	159	0	5	25	9	30	15
Long-term care	52	0	0	7	2	7	0
Childcare centers	253	0	7	22	15	28	11
Schools	194	0	5	17	12	22	9
Animal Facilities	**1**	**0**	**1**	**0**	**1**	**1**	**0**
Animal Shelters	1	0	1	0	1	1	0
Total	**914**	**0**	**22**	**90**	**47**	**109**	**43**

Exposure by City

The following discussion presents the results of the exposure analysis for each city in the ART project area. Summary tables of the number of residents, employees, property value, and community facilities and services exposed by city are provided. Note that the percent (of residents, employees, property value, etc.) presented is based on the portion of each city within the ART project area rather than based on city totals.

Alameda

The entire City of Alameda is within the ART project area, and a fairly large portion of residents is at risk of exposure to sea level rise (Table 3). While only 1,100 people, or 2% of the population, will be exposed to the daily high tide with 16 inches of sea level rise, over 10% will be exposed to storm event flooding, and over 40% will be exposed to wind waves. With 55 inches of sea level rise, exposure increases dramatically: 20% of the population would be exposed to the daily high tide, 45% to storm event flooding, and nearly 60% to wind waves. While the number of employees working in Alameda is much lower than the number of residents, there are similar trends in employee exposure. Only 18 employees, or 2%, would be exposed to the daily high tide with 16 inches of sea level rise, but 15% would be exposed to the daily high tide with 55 inches of sea level rise, and this increases to nearly half of all employees, if there is a storm event. Wind wave exposure was not analyzed.

According to HAZUS, replacement costs for buildings and their contents in the City of Alameda range from $91 million exposed to the daily high tide with 16 inches of sea level rise, to $2.9 billion exposed to storm events and wind waves with 55 inches of sea level rise ($2.3 billion exposed to storm events and an additional $550 million exposed to wind waves only). Using the Assessor's data, between $370 million (daily high tide with 16 inches of sea level rise) and $5.8 billion ($4.6 billion exposed to storm events and $1.2 billion exposed to wind waves only with 55 inches of sea level rise) is exposed.

Table 3. Residents, Employees, and Property Values (in millions of dollars) exposed to 16 and 55 inches of sea level rise in the City of Alameda.

		16" SLR			55" SLR		
		Daily High Tide	Storm Event		Daily High Tide	Storm Event	
	City total*	Exposed	Exposed	Exposed to wind waves only	Exposed	Exposed	Exposed to wind waves only
Residents	**72,259**						
Number		1,103	8,619	21,757	14,227	32,416	9,045
Percent		2%	12%	30%	20%	45%	13%
Employees	**21,428**						
Number		18	1,716	--	3,220	9,991	--
Percent		0%	8%	--	15%	47%	--
Replacement Costs ($M) (HAZUS)	**$4,450**						
Replacement costs		$91	$645	$1,525	$1,020	$2,370	$550
Percent		2%	15%	34%	23%	53%	12%
Assessed value ($M)	**$8,877**						
Assessed value		$370	$1,807	$2,816	$2,665	$4,589	$1,211
Percent		4%	20%	32%	30%	52%	14%

* Total is for portion of the city in the ART project area

There are six emergency response facilities in the City of Alameda – one police station, four fire stations, and one hospital (Table 4). With 16 inches of sea level rise, none of these facilities are exposed to the daily high tide, but Fire Station 4 is exposed to storm event flooding (Figure 2). With 55 inches of sea level rise, only Fire Station 4 is exposed to high tide inundation and storm event flooding.

Figure 2. Fire Station 4 in the City of Alameda.

There are six facilities serving at-risk populations: three health care facilities, two food banks, and one jail. There are no homeless shelters or group homes. Two health care facilities and one food bank are exposed to wind waves with 16 inches of sea level rise. These same facilities are exposed to storm event flooding with 55 inches of sea level rise, and an additional health care facility is exposed to wind waves only with 55 inches of sea level rise. The one jail is not exposed to any of the scenarios.

There are 76 facilities in Alameda serving vulnerable, less mobile populations such as seniors, the infirm, and children. Three long-term care facilities are cross-listed with other facilities (one health care facility, one hospital, and one senior housing facility), and nine schools are cross-listed with childcare facilities. None of the 76 facilities are exposed to the daily high tide with 16 inches of sea level rise, but several schools, childcare facilities, and senior housing facilities are exposed to storm event flooding. With 55 inches of sea level rise, over 25% of facilities are exposed to the daily high tide, and over half – including all of the long term care facilities and all but two senior housing facilities – are exposed to storm event flooding. Several more are exposed to wind waves only.

The one animal shelter in Alameda is exposed to all of the future climate scenarios evaluated except for the daily high tide with 16 inches of sea level rise.

Table 4. Number of community facilities and services exposed to 16 and 55 inches of sea level rise in the City of Alameda.

		16" SLR			55" SLR		
		Daily High Tide	Storm Event		Daily High Tide	Storm Event	
Type of facility	City total*	Exposed	Exposed	Exposed to wind waves only	Exposed	Exposed	Exposed to wind waves only
Emergency response	**6**	**0**	**1**	**0**	**1**	**1**	**1**
Hospitals	1	0	0	0	0	0	0
Police stations	1	0	0	0	0	0	0
Fire stations	4	0	1	0	1	1	1
Serving at-risk populations	**6**	**0**	**0**	**3**	**0**	**3**	**1**
Health care facilities	3	0	0	2	0	2	1
Homeless shelters	0	--	--	--	--	--	--
Group homes	0	--	--	--	--	--	--
Food banks	2	0	0	1	0	1	0
Jails	1	0	0	0	0	0	0
Serving vulnerable, less mobile populations	**76**	**0**	**12**	**28**	**21**	**40**	**7**
Senior housing	13	0	3	8	6	11	2
Long-term care	7	0	0	7	2	7	0
Childcare centers	30	0	5	6	8	11	3
Schools	26	0	4	7	5	11	2
Animal Facilities	**1**	**0**	**1**	**0**	**1**	**1**	**0**
Animal Shelters	1	0	1	0	1	1	0
Total	**89**	**0**	**14**	**31**	**23**	**45**	**9**

* Total is for portion of the city in the ART project area

Emeryville

There are nearly 7,000 people in the ART project area in the City of Emeryville. Of these, fewer than 150 will be exposed to the daily high tide or storm event flooding with 16 or 55 inches of sea level rise (Table 5). However, approximately 700 people will be exposed to wind waves with 16 inches of sea level rise, and nearly 2,000 will be exposed to wind waves with 55 inches of sea level rise. Over 18,000 people work in the ART project area in Emeryville, reflecting the commercial and industrial nature of this city. None of these employees are exposed to the daily high tide or storm event flooding with 16 inches of sea level rise; exposure to wind waves was not analyzed. With 55 inches of sea level rise, relatively few employees would be exposed to the daily high tide, but nearly 4,000, or 20% of employees would be exposed to storm event flooding, and an even higher percentage can be assumed to be exposed to wind waves.

The HAZUS replacement costs range from $4 million exposed to the daily high tide with 16 inches of sea level rise, to $316 million exposed to storm events and wind waves with 55 inches of sea level rise ($69 million exposed to storm events and $247 million exposed to wind waves only). Using the Assessor's data, between $86 million (daily high tide with 16 inches of sea level rise) and $1.3 billion ($726 million exposed to storm events and $545 million exposed to wind waves only with 55 inches of sea level rise) is exposed.

Table 5. Residents, Employees, and Property Values (in millions of dollars) exposed to 16 and 55 inches of sea level rise in the ART project area in Emeryville.

		16" SLR			55" SLR		
		Daily High Tide	Storm Event		Daily High Tide	Storm Event	
	Total*	Exposed	Exposed	Exposed to wind waves only	Exposed	Exposed	Exposed to wind waves only
Residents	6,882						
Number		29	56	662	96	138	1,771
Percent		0%	1%	10%	1%	2%	26%
Employees	18,349						
Number		0	0	--	108	3,740	--
Percent		0%	0%	--	1%	20%	--
Replacement Costs ($M) (HAZUS)	910						
Replacement costs		4	6	106	11	69	247
Percent		0%	1%	12%	1%	8%	27%
Assessed value ($M)	3,512						
Assessed value		86	89	615	112	726	545
Percent		2%	3%	18%	3%	21%	16%

* Total is for portion of the city in the ART project area

There are three emergency response facilities in the ART project area in Emeryville – two fire stations and a police station (Table 6). The police station and one fire station are located on Powell Street, west of I-80/I-580. They are not exposed to the daily high tide or storm event flooding with 16 inches of sea level rise, but the fire station is exposed to wind waves. With 55 inches of sea level rise, the police station is exposed to storm event flooding and wind waves, and the fire station is exposed to high tide inundation and storm event flooding. The other fire station, on Hollis Street, is not exposed to any of the scenarios evaluated.

Three facilities in the ART project area in Emeryville serve at-risk populations, all of which are health care facilities. Two of these facilities are exposed to wind waves with 16 inches of sea level rise and storm event flooding with 55 inches of sea level rise. All three facilities are exposed to wind waves with 55 inches of sea level rise. There are nine facilities in the area that serve vulnerable, less mobile populations – one senior housing facility, four childcare centers, and four schools. One location houses both a childcare center and a school. The senior housing facility is exposed to wind waves with 55 inches of sea level rise only; no other facilities are exposed to any of the scenarios evaluated.

Table 6. Number of community facilities and services exposed to 16 and 55 inches of sea level rise in the ART project area in Emeryville.

		16" SLR			55" SLR		
		Daily High Tide	Storm Event		Daily High Tide	Storm Event	
Type of facility	City total*	Exposed	Exposed	Exposed to wind waves only	Exposed	Exposed	Exposed to wind waves only
Emergency response	**3**	**0**	**0**	**1**	**1**	**2**	**0**
Hospitals	0	--	--	--	--	--	--
Police stations	1	0	0	0	0	1	0
Fire stations	2	0	0	1	1	1	0
Serving at-risk populations	**3**	**0**	**0**	**2**	**0**	**2**	**1**
Health care facilities	3	0	0	2	0	2	1
Homeless shelters	0	--	--	--	--	--	--
Group homes	0	--	--	--	--	--	--
Food banks	0	--	--	--	--	--	--
Jails	0	--	--	--	--	--	--
Serving vulnerable, less mobile populations	**9**	**0**	**0**	**0**	**0**	**0**	**1**
Senior housing	1	0	0	0	0	0	1
Long-term care	0	--	--	--	--	--	--
Childcare centers	4	0	0	0	0	0	0
Schools	4	0	0	0	0	0	0
Animal Facilities	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Animal Shelters	0	--	--	--	--	--	--
Total	**15**	**0**	**0**	**3**	**1**	**4**	**2**

* Total is for portion of the city in the ART project area

Hayward

Approximately 140,000 Hayward residents live in the ART project area. Relatively few would be exposed to the daily high tide with 16 or 55 inches of sea level rise, or storm event flooding with 16 inches (Table 7). Slightly fewer then 5,000 residents would be exposed to 16 inches of sea level rise during a storm event with wind waves. Over 5,000 residents would be exposed to storm event flooding with 55 inches, and over 10,000 are exposed to wind waves with 55 inches of sea level rise. Approximately 60,000 people work in the ART project area in Hayward. With 16 inches of sea level rise, none of these employees would be exposed to the daily high tide, and approximately 700 would be exposed to storm events. With 55 inches of sea level rise, approximately 2,500 and 10,000 would be exposed to flooding from the daily high tide and storm events, respectively. Exposure to wind waves was not analyzed.

The replacement value of property in the ART project area in Hayward is approximately $8 billion according to the HAZUS model, and property values are just over $16 billion using the Assessor's data. Based on HAZUS, replacement costs range from $75 million exposed to the daily high tide with 16 inches of sea level rise, to $1.5 billion exposed to storm events and wind waves with 55 inches of sea level rise ($1.1 billion exposed to storm events and $340 million exposed to wind waves only). Using the Assessor's data, property values exposed range from $48 million exposed to the daily high tide with 16 inches of sea level rise, to $3.2 billion exposed to storm events and wind waves with 55 inches of sea level rise ($2.5 billion exposed to storm events and $748 million exposed to wind waves only).

Table 7. Residents, Employees, and Property Values (in millions of dollars) exposed to 16 and 55 inches of sea level rise in the ART project area in Hayward.

		16" SLR			**55" SLR**		
		Daily High Tide	Storm Event		Daily High Tide	Storm Event	
	City total*	Exposed	Exposed	Exposed to wind waves only	Exposed	Exposed	Exposed to wind waves only
Residents	140,030						
Number		82	167	4,832	187	5,250	5,287
Percent		0%	0%	3%	0%	4%	4%
Employees	60,310						
Number		0	740	--	2,525	9,662	--
Percent		0%	1%	--	4%	16%	--
Replacement Costs ($M) (HAZUS)	$8,110						
Replacement costs		$75	$258	$694	$373	$1,120	$340
Percent		1%	3%	9%	5%	14%	4%
Assessed value *($M)*	$16,315						
Assessed value		$48	$743	$1,727	$1,203	$2,466	$748
Percent		0%	5%	11%	7%	15%	5%

* Total is for portion of the city in the ART project area

There are six emergency response facilities in the ART project area in Hayward: two hospitals, two police stations, and two fire stations (Table 8). These facilities are not exposed to any of the scenarios evaluated. Forty-six facilities serve at-risk populations: 32 health care facilities, two homeless shelters, four group homes, seven food banks, and one jail, which is co-located with one of the police stations. Of these facilities, two health care facilities are exposed to wind waves with 16 inches of sea level rise, and with 55 inches of sea level rise these same facilities are exposed to the daily high tide and storm event flooding. One hundred thirty five facilities serve vulnerable, less mobile populations: 46 senior housing facilities, 16 long-term care facilities, 34 childcare centers, and 39 schools. Fourteen long-term care facilities are co-located with a health care or senior housing facility, and 14 locations house schools and childcare centers. Only five of the 135 facilities are exposed to wind waves with 16 inches of sea level rise, and to storm event flooding with 55 inches of sea level rise. An additional three are exposed to wind waves with 55 inches of sea level rise.

Table 8. Number of community facilities and services exposed to 16 and 55 inches of sea level rise in the ART project area in Hayward.

		16" SLR			55" SLR		
		Daily High Tide	Storm Event		Daily High Tide	Storm Event	
Type of facility	City total*	Exposed	Exposed	Exposed to wind waves only	Exposed	Exposed	Exposed to wind waves only
Emergency response	**6**	**0**	**0**	**0**	**0**	**0**	**0**
Hospitals	**2**	0	0	0	0	0	0
Police stations	**2**	0	0	0	0	0	0
Fire stations	**2**	0	0	0	0	0	0
Serving at-risk populations	**46**	**0**	**0**	**2**	**2**	**2**	**0**
Health care facilities	**32**	0	0	2	2	2	0
Homeless shelters	**2**	0	0	0	0	0	0
Group homes	**4**	0	0	0	0	0	0
Food banks	**7**	0	0	0	0	0	0
Jails	**1**	0	0	0	0	0	0
Serving vulnerable, less mobile populations	**135**	**0**	**0**	**5**	**0**	**5**	**3**
Senior housing	**46**	0	0	3	0	3	2
Long-term care	**16**	0	0	0	0	0	0
Childcare centers	**34**	0	0	1	0	1	1
Schools	**39**	0	0	1	0	1	0
Animal Facilities	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Animal Shelters	**0**	--	--	--	--	--	--
Total	**187**	**0**	**0**	**7**	**2**	**7**	**3**

* Total is for portion of the city in the ART project area

Oakland

There are approximately 400,000 residents living in the ART project area in Oakland. Very few are exposed to the daily high tide with 16 inches of sea level rise, and approximately 6,000, or two percent, are exposed to wind waves (Table 9). Roughly the same amount are exposed to storm event flooding with 55 inches of sea level rise, and nearly 15,000, or four percent, are exposed to wind waves. Approximately 150,000 people work in Oakland. With 16 inches of sea level rise, fewer than 1,000 employees are exposed to the daily high tide, and approximately 4,000, or two percent, are exposed to storm event flooding. With 55 inches of sea level rise, over 12,000 employees, or eight percent, are exposed to storm event flooding, and over 32,000, or 21%, are exposed to wind waves.

The replacement costs of property in the ART project area in Oakland are approximately $22 billion according to the HAZUS model, and property values are $38 billion using the Assessor's data. Based on HAZUS, replacement costs range from $104 million exposed to the daily high tide with 16 inches of sea level rise, to $2.9 billion exposed to storm events and wind waves with 55 inches of sea level rise ($1.9 billion exposed to storm events and $1 billion exposed to wind waves only). Using the Assessor's data, the property value exposed ranges from $182 million for the daily high tide with 16 inches of sea level rise, to $3 billion exposed to storm events and wind waves with 55 inches of sea level rise ($2.4 billion exposed to storm events and $621 million exposed to wind waves only).

Table 9. Residents, Employees, and Property Values (in millions of dollars) exposed to 16 and 55 inches of sea level rise in the ART project area in Oakland.

		16" SLR			55" SLR		
		Daily High Tide	Storm Event		Daily High Tide	Storm Event	
	City total*	Exposed	Exposed	Exposed to wind waves only	Exposed	Exposed	Exposed to wind waves only
Residents	399,484						
Number		16	233	5,732	1,370	5,840	8,991
Percent		0%	0%	1%	0%	2%	2%
Employees	151,962						
Number		993	3,599	--	12,486	32,431	--
Percent		1%	2%	--	8%	21%	--
Replacement Costs ($M) (HAZUS)	22,176						
Replacement costs		104	256	1,664	678	1,960	1,010
Percent		1%	1%	8%	3%	9%	5%
Assessed value ($M)	38,171						
Assessed value		182	375	2,028	1,158	2,396	621
Percent		0%	1%	5%	3%	6%	2%

* Total is for portion of the city in the ART project area

There are thirteen emergency response facilities in the ART project area in Oakland: four hospitals, one police station and eight fire stations (Table 10). Two fire stations are exposed to wind waves with 16 inches of sea level rise. With 55 inches of sea level rise, these same stations are exposed to storm event flooding, and one additional fire station is exposed to wind waves. None of the other facilities are exposed to any of the scenarios evaluated.

There are 133 facilities serving at-risk populations: 87 health care facilities, 12 homeless shelters, 19 group homes, 14 food banks, and one jail. With 16 inches of sea level rise, only one facility is exposed to storm event flooding and seven are exposed to wind waves. With 55 inches of sea level rise, two are exposed to the daily high tide, seven are exposed to storm event flooding, and four additional facilities are exposed to wind waves only. Two hundred ninety three facilities serving vulnerable, less mobile populations are in the ART project area in Oakland: 45 senior housing facilities, 21 long-term care facilities, 146 childcare centers, and 81 schools. With 16 inches of sea level rise, only one is exposed to storm events and eight are exposed to wind waves only. With 55 inches of sea level rise, two facilities are exposed to the daily high tide, nine are exposed to storm event flooding, and an additional 12 are exposed to wind waves only.

Several facilities in Oakland provide multiple services to the community. For example, all of the hospitals are also listed as other types of health care facilities, and five senior housing facilities and seven long-term care facilities are cross-listed. Thirteen schools are co-located with childcare centers or other services, and a number of food banks are located at the same address as homeless shelters or health care facilities.

Table 10. Number of community facilities and services exposed to 16 and 55 inches of sea level rise in the ART project area in Oakland.

		16" SLR			55" SLR		
		Daily High Tide	Storm Event		Daily High Tide	Storm Event	
Type of facility	City total*	Exposed	Exposed	Exposed to wind waves only	Exposed	Exposed	Exposed to wind waves only
Emergency response	**13**	**0**	**0**	**2**	**0**	**2**	**1**
Hospitals	**4**	0	0	0	0	0	0
Police stations	**1**	0	0	0	0	0	0
Fire stations	**8**	0	0	2	0	2	1
Serving at-risk populations	**133**	**0**	**1**	**7**	**2**	**7**	**4**
Health care facilities	**87**	0	1	4	2	4	2
Homeless shelters	**12**	0	0	2	0	2	0
Group homes	**19**	0	0	0	0	0	0
Food banks	**14**	0	0	1	0	1	2
Jails	**1**	0	0	0	0	0	0
Serving vulnerable, less mobile populations	**293**	**0**	**1**	**8**	**2**	**9**	**12**
Senior housing	**45**	0	0	0	0	0	3
Long-term care	**21**	0	0	0	0	0	0
Childcare centers	**146**	0	0	6	0	6	4
Schools	**81**	0	1	2	2	3	5
Animal Facilities	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Animal Shelters	**0**	--	--	--	--	--	--
Total	**439**	**0**	**2**	**17**	**4**	**18**	**17**

* Total is for portion of the city in the ART project area

San Leandro

Nearly 80,000 people live in the ART project area in San Leandro. With 16 inches of sea level rise, a few hundred are exposed to the daily high tide, over 3,000 are exposed to storm event flooding, and over 9,000, or 12%, are exposed to wind waves (Table 11). With 55 inches of sea level rise, over 4,000 are exposed to the daily high tide, nearly 10,000 are exposed to storm event flooding, and over 15,000, or 20%, are exposed to wind waves. There are approximately 35,000 people who work in the ART project area in San Leandro. No employees are exposed to the daily high tide with 16 inches of sea level rise, but over 2,000, or seven percent, are exposed to storm event flooding. Roughly the same number are exposed to the daily high tide with 55 inches of sea level rise, and nearly 8,000, or 21%, are exposed to storm event flooding. Exposure to wind waves was not analyzed.

According to the HAZUS model, there are approximately $5 billion of replacement costs in the ART project area in San Leandro. Between $23 million (daily high tide with 16 inches of sea level rise) and $1.1 billion ($668 million exposed to storm events and $472 million exposed to wind waves only with 55 inches of sea level rise) of replacement costs are exposed to the scenarios analyzed. The assessed value of property is nearly $10 billion, of which $8 million (daily high tide with 16 inches of sea level rise) to $2 billion ($1.6 billion exposed to storm events and $415 million exposed to wind waves only with 55 inches of sea level rise) is exposed.

Table 11. Residents, Employees, and Property Values (in millions of dollars) exposed to 16 and 55 inches of sea level rise in the ART project area in San Leandro.

		16" SLR			55" SLR		
		Daily High Tide	Storm Event		Daily High Tide	Storm Event	
	City total*	Exposed	Exposed	Exposed to wind waves only	Exposed	Exposed	Exposed to wind waves only
Residents	79,452						
Number		356	3,220	6,227	4,246	9,732	5,734
Percent		0%	4%	8%	5%	12%	7%
Employees	35,690						
Number		0	2,494	--	2,984	7,673	--
Percent		0%	7%	--	8%	21%	--
Replacement Costs ($M) (HAZUS)	5,218						
Replacement costs		23	227	510	316	668	472
Percent		0%	4%	10%	6%	13%	9%
Assessed value ($M)	9,890						
Assessed value		8	464	1,097	802	1,607	415
Percent		0%	5%	11%	8%	16%	4%

* Total is for portion of the city in the ART project area

There are three hospitals, one police station, and three fire stations in the ART project area in San Leandro (Table 12). One fire station is exposed to all of the sea level rise scenarios except for the daily high tide with 16 inches of sea level rise. There are 23 facilities serving at-risk populations: 16 health care facilities, two group homes, four food banks, and one jail, which is co-located with the police station. Of these, only one health care facility is exposed to the most extreme scenario, wind waves with 55 inches of sea level rise. Eighty-one facilities serve vulnerable, less mobile populations: 23 senior housing facilities, eight long-term care facilities, 26 childcare centers, and 24 schools. Two long-term care facilities are co-located with other health care facilities, and seven locations house schools and childcare centers. Two facilities are exposed to storm event flooding with 16 inches of sea level rise, and an additional six are exposed to wind waves only. With 55 inches of sea level rise, two facilities are exposed to the daily high tide, eight are exposed to storm event flooding, and four additional facilities are exposed to wind waves only.

Table 12. Number of community facilities and services exposed to 16 and 55 inches of sea level rise in the ART project area in San Leandro.

		16" SLR			**55" SLR**		
		Daily High Tide	Storm Event		Daily High Tide	Storm Event	
Type of facility	City total*	Exposed	Exposed	Exposed to wind waves only	Exposed	Exposed	Exposed to wind waves only
Emergency response	**7**	**0**	**1**	**0**	**1**	**1**	**0**
Hospitals	**3**	0	0	0	0	0	0
Police stations	**1**	0	0	0	0	0	0
Fire stations	**3**	0	1	0	1	1	0
Serving at-risk populations	**23**	**0**	**0**	**0**	**0**	**0**	**1**
Health care facilities	**16**	0	0	0	0	0	1
Homeless shelters	**0**	--	--	--	--	--	--
Group homes	**2**	0	0	0	0	0	0
Food banks	**4**	0	0	0	0	0	0
Jails	**1**	0	0	0	0	0	0
Serving vulnerable, less mobile populations	**81**	**0**	**2**	**6**	**2**	**8**	**4**
Senior housing	**23**	0	2	2	2	4	1
Long-term care	**8**	0	0	0	0	0	0
*Childcare centers***	**26**	0	0	2	0	2	1
*Schools****	**24**	0	0	2	0	2	2
Animal Facilities	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Animal Shelters	**0**	--	--	--	--	--	--
Total	**111**	**0**	**3**	**6**	**3**	**9**	**5**

* Total is for portion of the city in the ART project area

San Lorenzo

Approximately 22,000 people live in the ART project area in San Lorenzo. Very few are exposed to the daily high tide or storm event flooding with 16 inches of sea level rise, or the daily high tide with 55 inches of sea level rise (Table 13). Nearly 3,000 people are exposed to wind waves with 16 inches and storm event flooding with 55 inches of sea level rise. Over 5,000 people, or 24%, are exposed to wind waves with 55 inches of sea level rise. Of the roughly 2,500 people working in San Lorenzo, only 20 are exposed to storm event flooding with 55 inches of sea level rise, the most extreme scenario analyzed for this group of people.

According to the HAZUS model, there are $1 billion of replacement costs in the ART project area in San Lorenzo, of which $2 million (daily high tide with 16 inches of sea level rise) to $282 million ($172 million exposed to storm events and $110 million exposed to wind waves only with 55 inches of sea level rise) are exposed to the various sea level rise scenarios analyzed. The assessed value of property in the area is approximately $2.3 billion. Between $1 million (daily high tide with 16 inches of sea level rise) and $551 million ($373 million exposed to storm events and $178 million exposed to wind waves only with 55 inches of sea level rise) of this property value is exposed to sea level rise.

Table 13. Residents, Employees, and Property Values (in millions of dollars) exposed to 16 and 55 inches of sea level rise in the ART project area in San Lorenzo.

		16" SLR			55" SLR		
		Daily High Tide	Storm Event		Daily High Tide	Storm Event	
	City total*	Exposed	Exposed	Exposed to wind waves only	Exposed	Exposed	Exposed to wind waves only
Residents	21,898						
Number		13	177	2,451	200	2,950	2,387
Percent		0%	1%	11%	1%	14%	11%
Employees	2,685						
Number		0	0	--	7	20	--
Percent		0%	0%	--	0%	1%	--
Replacement Costs ($M) (HAZUS)	1,004						
Replacement costs		2	22	133	27	172	110
Percent		0%	2%	13%	3%	17%	11%
Assessed value ($M)	2,264						
Assessed value		1	49	304	76	373	178
Percent		0%	2%	13%	3%	16%	8%

* Total is for portion of the city in the ART project area

There are no emergency response facilities in the ART project area in San Lorenzo. None of the three facilities that serve at-risk populations – one health care facility and two food banks – are exposed to any of the scenarios analyzed. There are 30 facilities that serve vulnerable, less mobile populations: eight senior housing facilities, nine childcare centers and 13 schools (Table 14). Five of the facilities are co-located schools and childcare facilities. Of these 30 facilities, one is exposed to storm event flooding with 16 inches of sea level rise, and an additional five are exposed to wind waves only. With 55 inches of sea level rise, four are exposed to the daily high tide, six are exposed to storm event flooding, and two more are exposed to wind waves only.

Table 14. Number of community facilities and services exposed to 16 and 55 inches of sea level rise in the ART project area in San Lorenzo.

		16" SLR			55" SLR		
		Daily High Tide	Storm Event		Daily High Tide	Storm Event	
Type of facility	City total*	Exposed	Exposed	Exposed to wind waves only	Exposed	Exposed	Exposed to wind waves only
Emergency response	**0**	**--**	**--**	**--**	**--**	**--**	**--**
Hospitals	**0**	--	--	--	--	--	--
Police stations	**0**	--	--	--	--	--	--
Fire stations	**0**	--	--	--	--	--	--
Serving at-risk populations	**3**	**0**	**0**	**0**	**0**	**0**	**0**
Health care facilities	**1**	0	0	0	0	0	0
Homeless shelters	**0**	--	--	--	--	--	--
Group homes	**0**	--	--	--	--	--	--
Food banks	**2**	0	0	0	0	0	0
Jails	**0**	--	--	--	--	--	--
Serving vulnerable, less mobile populations	**30**	**0**	**1**	**5**	**4**	**6**	**2**
Senior housing	**8**	0	0	1	0	1	0
Long-term care	**0**	--	--	--	--	--	--
*Childcare centers***	**9**	0	1	4	4	5	2
*Schools****	**13**	0	0	0	0	0	0
Animal Facilities	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Animal Shelters	**0**	--	--	--	--	--	--
Total	**33**	**0**	**1**	**5**	**4**	**6**	**2**

* Total is for portion of the city in the ART project area

Union City

Nearly 67,000 people live in the ART project area in Union City. While only one percent is exposed to the daily high tide with 16 inches of sea level rise, nearly 5,000, or seven percent is exposed to storm event flooding, and over 25,000, or 38%, are exposed to wind waves (Table 15). With 55 inches of sea level rise nearly 18,000, or 27%, are exposed to the daily high tide; almost 40% are exposed to storm event flooding, and over 34,000, or 51%, are exposed to wind waves. Just over 19,000 people work in the ART project area in Union City. Of these, approximately 700, or four percent, are exposed to storm event flooding with 16 inches of sea level rise. With 55 inches of sea level rise, just over 1,000 employees, or six percent, are exposed to the daily high tide, and 4,500, or 24%, are exposed to storm event flooding. Employee exposure to wind waves was not analyzed.

According to the HAZUS model, there are 3.2 billion dollars of replacement costs in the ART project area in Union City, of which $26 million (daily high tide with 16 inches of sea level rise) to $1.6 billion dollars ($1.2 billion exposed to storm event flooding, and an additional 380 million dollars exposed to wind waves with 55 inches of sea level rise) are exposed. The assessed value of property in the area is $7.6 billion, with zero (daily high tide with 16 inches of sea level rise) to $3.7 billion ($3 billion exposed to storm event flooding and an additional $766 million exposed to wind waves with 55 inches of sea level rise) exposed.

Table 15. Residents, Employees, and Property Values (in millions of dollars) exposed to 16 and 55 inches of sea level rise in the ART project area in Union City.

		16" SLR			55" SLR		
		Daily High Tide	Storm Event		Daily High Tide	Storm Event	
	ART project area total	Exposed	Exposed	Exposed to wind waves only	Exposed	Exposed	Exposed to wind waves only
Residents	66,869						
Number		353	4,849	20,652	17,940	25,722	8,441
Percent		1%	7%	31%	27%	39%	13%
Employees	19,210						
Number		0	716	--	1,197	4,562	--
Percent		0%	4%	--	6%	24%	--
Replacement Costs ($M) (HAZUS)	3,259						
Replacement costs		26	220	940	716	1,200	380
Percent		1%	7%	29%	22%	37%	12%
Assessed value ($M)	7,563						
Assessed value		0	589	2,428	1,859	2,964	766
Percent		0%	8%	32%	25%	39%	10%

* Total is for portion of the city in the ART project area

There are two emergency response facilities – both of which are fire stations – in the ART project area in Union City (Table 16). One station is exposed to storm event flooding with 16 inches of sea level rise, and another is exposed to wind waves only. With 55 inches of sea level rise, one is exposed to the daily high tide, and both are exposed to storm event flooding and wind waves. There are three facilities serving at-risk populations. One, a health care facility, is exposed to wind waves only with 16 inches of sea level rise. With 55 inches of sea level rise, it is exposed to storm event flooding. There are 34 facilities serving vulnerable, less mobile populations: 23 senior housing facilities, four childcare centers, and seven schools. Two locations have childcare centers and schools. Of the 34 facilities, one is exposed to storm event flooding with 16 inches of sea level rise, and 19, including 11 senior housing facilities, are exposed to wind waves only. With 55 inches of sea level rise, nine facilities are exposed to the daily high tide, including three childcare facilities and five schools. Nineteen are exposed to storm event flooding, and six are exposed to wind waves only.

Table 16. Number of community facilities and services exposed to 16 and 55 inches of sea level rise in the ART project area in Union City.

		16" SLR			55" SLR		
		Daily High Tide	Storm Event		Daily High Tide	Storm Event	
Type of facility	City total*	Exposed	Exposed	Exposed to wind waves only	Exposed	Exposed	Exposed to wind waves only
Emergency response	**2**	**0**	**1**	**1**	**1**	**2**	**0**
Hospitals	**0**	--	--	--	--	--	--
Police stations	**0**	--	--	--	--	--	--
Fire stations	**2**	0	1	1	1	2	0
Serving at-risk populations	**4**	**0**	**0**	**1**	**0**	**1**	**0**
Health care facilities	**2**	0	0	1	0	1	0
Homeless shelters	**0**	--	--	--	--	--	--
Group homes	**1**	0	0	0	0	0	0
Food banks	**1**	0	0	0	0	0	0
Jails	**0**	--	--	--	--	--	--
Serving vulnerable, less mobile populations	**34**	**0**	**1**	**19**	**9**	**19**	**6**
Senior housing	**23**	0	0	11	1	11	6
Long-term care	**0**	--	--	--	--	--	--
*Childcare centers** *	**4**	0	1	3	3	3	0
*Schools*** *	**7**	0	0	5	5	5	0
Animal Facilities	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Animal Shelters	**0**	--	--	--	--	--	--
Total	**40**	**0**	**2**	**21**	**10**	**22**	**6**

* Total is for portion of the city in the ART project area

Sensitivity and Adaptive Capacity

Sensitivity refers to the degree to which an asset or entire system (e.g., a senior housing facility, or jobs within a city) would be physically or functionally impaired if exposed to a climate impact. Adaptive capacity is the ability for an asset or system to accommodate or adjust to a climate impact and maintain or quickly resume its primary function. This chapter addresses a very broad cross section of assets, ranging from private residences to facilities housing seniors who may have limited mobility, to police and fire stations that would be heavily relied on in a flood emergency. Because of the diversity across and within these categories, this section does not provide a detailed analysis of the sensitivity of every asset, or even every category, but rather provides an overview of how the ART project area's residents, employees, facilities, and services are sensitive to sea level rise, and describes where adaptive capacity exists.

Residents and Employees
The sensitivity and adaptive capacity of the people who live and work in the ART project area will depend on a number of factors, including economic status, level of education, health and physical mobility, ownership of a home or car, and proficiency in English. These factors can influence the degree to which individuals, households, neighborhoods and even communities are vulnerable. An analysis of demographic factors in the ART project area and their relationship to community vulnerability is discussed in detail in a companion piece to this report[6].

Beyond these factors, individuals are often sensitive to, and have limited capacity to either adjust to or accommodate, a climate impact such as flooding. Having to leave one's home, even for a short period, can have a devastating effect on both individuals and families. For many, especially those in the Bay Area where available housing is expensive and difficult to find, losing housing even temporarily can be a significant hardship that is hard to overcome. Often there is limited capacity or opportunity to find adequate and affordable replacement housing that is near the jobs, schools, services, and facilities that individuals and households rely on.

Individuals that rent housing may be particularly sensitive, as they may not be able to influence the owners to improve the property to better withstand flooding, or to respond to a flood event if it does occur, for example by quickly drying and replacing damaged materials. Renters may also lack insurance that could provide assistance with replacing damaged personal items or providing an alternative place to live. In all cases, for both homeowners and renters alike, in addition to the burden of relocation, the loss of all or even a portion of one's personal belongings – including photos, birth certificates, financial documents, valuables, and other treasured items – can have significant and lasting impacts. Often these items cannot be replaced, and in many cases personal and financial documents are necessary to begin recovering and rebuilding after a flood event.

In addition to the individual and household vulnerabilities discussed above, the people, property, and places that make up the neighborhoods in the ART project area are collectively sensitive to sea level rise and storm events, and have varying capacities to accommodate or adjust to impacts if they were to occur.

Residential neighborhoods, in particular, are both physically and functionally sensitive to inundation, flooding, and elevated groundwater levels. In general, most buildings are not designed or constructed to withstand flooding or rising groundwater. For example, buildings

[6] See "Addressing Social Vulnerability and Equity in Climate Change Adaptation Planning," available on the ART project website: http://www.adaptingtorisingtides.org/project-reports/.

with drywall are particularly sensitive as drywall wicks water upward, meaning damage can occur well above the actual level of flooding. In addition, drywall and other materials, such as plaster can become fragile if exposed to water for long periods of time, and even if dried, they cannot easily be decontaminated and generally must be demolished and replaced. Other common construction materials, such as wood, may not suffer structural damage from flooding, but mold and other organisms can flourish in the wet, post-flood environment. Wood structures must be thoroughly and fairly immediately dried out or they will decay, requiring demolition and replacement.

In addition to flooding due to extreme tides or storm events, higher groundwater levels that may result from rising sea level will affect residential and other buildings that have underground components. Sump pumps are often used in areas that already have high groundwater to keep basements and underground areas such as storage or parking areas dry and functioning. As groundwater levels rise, underground areas, which are already sensitive to flooding, will be at greater risk. There are opportunities for underground areas to be improved to accommodate or adjust to rising groundwater, for example by installing new or larger pumps, or elevating or removing items that could be damaged if wet. However, long duration high groundwater events, especially if combined with power outages that cause pumps to cease functioning or if there is overland flooding at the same time, can ultimately not be accommodated.

While there is some capacity for individual buildings within neighborhoods to accommodate or adjust to flooding impacts, often this capacity is limited to short duration or less severe events. For example, sandbags can provide some level of protection to buildings and other facilities, and in some cases personal property or valuables can be moved to upper floors. Adaptive capacity could be increased if buildings are constructed or reconstructed with flood resistant materials, or if lower floors are raised above projected flood levels. However, these are costly and time-consuming efforts for property owners, and from the perspective of city- or region-wide adaptive capacity, there is no way to ensure that building owners will take these steps without some form of financial or regulatory incentives.

If protecting buildings and neighborhoods from flooding is not an option, in the short-term residents can evacuate and stay in hotels or shelters, and some businesses may be able to rent space or have workers telecommute. These solutions may not be viable over the long term, as hotels and shelters do not provide real redundancy, and many businesses require specialized equipment or storage space that is not immediately available elsewhere. Over the long term, and in the event of large scale flooding, many of the options that increase individuals' and neighborhoods' adaptive capacity will not be sustainable, and there will need to be coordinated action to improve resilience.

In general, neighborhoods are greater than the sum of their parts. Beyond the physical characteristics and conditions of buildings that comprise a neighborhood are the social networks that define how a neighborhood functions. This function is dependent on the people that live and work there, the relationships among them, and the ties that connect them. In many ways, how a neighborhood functions can either impart resilience or be the cause of vulnerability. A neighborhood with a strong social network that is tied together by individual relationships will have a lower overall sensitivity and higher adaptive capacity than a neighborhood where residents either do not know each other, or are not invested in the overall community good. For example, a neighborhood where residents have strong connections and can rely on each other in an urgent or emergency situation will be less sensitive, and will be more likely to find ways to adjust to or accommodate a climate impact such as a flood event than those responding on their own.

Neighborhood networks and resources can be both informal and formal. An example of a formal neighborhood network is the Community Emergency Response Team (CERT), one of which is run by Alameda County, and several others by cities in the ART project area.[7] The CERT program is a countrywide initiative that helps local agencies and other entities train citizens to respond to emergencies in their neighborhoods, particularly when official emergency responders are overwhelmed by a large-scale disaster. While training content and format differs from program to program, most include disaster medical operations, fire suppression, and HAZMAT awareness. Neighborhoods where individuals have been trained to respond to disasters will be better equipped to respond to an extreme tide or storm events, as will those with informal, social connections among neighbors. On the other hand, in a neighborhood without these resources and connections, each individual or household would be on their own to their own to face the impact separately.

In addition, the social networks and ties that connect individuals in a neighborhood can themselves be sensitive and have limited adaptive capacity. For example, a storm event that floods a neighborhood and causes residents to be relocated to disparate locations, either temporarily or permanently, can sever even long-standing relationships, disrupting the social network that imparted collective strength and resilience. The capacity to reconnect or rebuild these ties will depend, ultimately, on the duration of the event, and the strength and will of the residents that return to the neighborhood.

Facilities and Services

Facilities that provide key community services will have similar physical sensitivities to those discussed above. The services these facilities provide will be sensitive to inundation, flooding, and elevated groundwater depending on the type of facility and the role it serves in the community. The different facilities will also have varying degrees of adaptive capacity. The ability to accommodate or adjust to an impact if it does occur will depend in part on the type of facility and service it provides to the community. These differences are described in more detail below.

Emergency Facilities

Emergency facilities will have similar physical sensitivities to flooding as other types of structures, but their functional sensitivities vary widely based on the nature of the facility. Many emergency facilities are large employers and sometimes shelter vulnerable populations, and therefore are sensitive in terms of the need to evacuate or safely shelter in place. These facilities also have two characteristics that can significantly increase their sensitivity: They usually contain highly sensitive, expensive, specialized equipment; and, they are critical in assisting others in the event of a disaster. Therefore, if exposed, these facilities are not only directly sensitive to potential physical damage or harm to people on-site, but are functionally sensitive in that their ability to serve the community as intended could be compromised.

An additional concern is that the function of an emergency facility can easily be compromised if access to and from it is disrupted. For example, patients must be able to get into hospitals, and fire and police vehicles must be able to leave stations to respond to emergencies. Therefore, the location and elevation of driveways and doorways is critical, as is the vulnerability of access roads. The facilities in the ART project area that are potentially exposed to flooding that have entrances at grade, critical equipment located on the first floor, or underground areas necessary to the function of the facility, will be sensitive to sea level rise impacts if they were to occur.

[7] Alameda County: https://www.citizencorps.gov/cc/showCert.do?cert&id=44855; City of Alameda: http://www.cityofalamedaca.gov/City-Hall/CERT; Emeryville: https://www.citizencorps.gov/cc/showCert.do?cert&id=43305; Hayward: https://www.citizencorps.gov/cc/showCert.do?cert&id=44015; Oakland: http://www.oaklandnet.com/fire/core/neighborhood.html

Emergency facilities do, however, have an inherent capacity to accommodate or adjust to impacts, which comes from the services these facilities provide. For example, fire stations are equipped to assist their communities with flooding and have access to portable pumps and power. In addition, as trained emergency responders, police and fire fighters should be individually prepared to safely evacuate if the stations are threatened. Where buildings have multiple stories, sensitive equipment may be able to be moved above the ground floor. In some cities, redundancy – that is, multiple hospitals and fire and police stations located within reasonable proximity – provides adaptive capacity. Even in cities with only one fire station or hospital, emergency responders are part of mutual aid agreements with other cities and their own county, and even other counties can be called upon to assist in the event of insufficient resources at the site of an emergency. For example, Union City contracts with the Alameda County Fire Department for fire services, but still owns and manages four fire stations. If one of Union City's facilities was out of service for an extended period of time, the city could coordinate with an adjacent city that is also affiliated with Alameda County Fire Department to provide coverage.

Beyond specific facilities that provide emergency response services on an ongoing basis, there are predetermined shelter-in-place locations identified in approved disaster plans. If there is an emergency in the ART project area, the Alameda County Emergency Operations Center, Alameda County Social Service Agency, and the affected cities would work with the American Red Cross to house displaced populations at local schools and other appropriate locations. Some of these shelter-in-place sites could, however, also be exposed to an extreme tide or storm event flooding. Because there are many sites identified across the county, though, and because they are not activated until the emergency occurs, there is probably adequate redundancy to sustain the overall function of temporarily housing displaced individuals.

At-risk populations

Facilities serving at-risk populations are particularly sensitive if people rely on them for shelter, for example facilities such as homeless shelters and group homes. In these cases, evacuation may be necessary and could result in the displacement of very vulnerable individuals. While temporary shelters may be available for residents and employees, some individuals – such as those with physical disabilities or special medical requirements – may not be able to be placed in these shelters, and alternative, appropriate facilities would need to be found. Facilities serving at-risk populations are often difficult to relocate due to the population served, the need to be located near transit, and the small operating budgets available to most organizations that run these types of shelters and homes. The capacity of facilities serving at-risk populations to accommodate or adjust to a flood event will depend on the preparation of carefully considered disaster plans, the adequacy of access to the temporary facility, access to appropriate facilities to temporarily house these populations, and the availability of equipment and trained personnel to assist in emergency response activities.

Other types of facilities serving at-risk populations, such as food banks and health clinics, will have physical and functional sensitivities. Sea level rise and storm events could result in the loss of supplies and equipment that would be difficult to move in an emergency and to replace during the response. Temporary re-location would also pose a challenge because in addition to the need for special equipment and facilities, transportation options to these facilities and access to transit is critical. Access to these facilities is also important and if impaired, would reduce or eliminate the role that they serve within the community.

In addition, the increased need for these types of services that may arise during a flooding emergency could be an added stressor that increases their sensitivity. For example, in the event of a flood, health clinics must continue to provide their regular services (i.e., to existing patients) while also preparing for and responding to a potentially large-scale disaster. Up to a point, health care systems have the capacity to bring in resources from other areas to assist them. However, this source of adaptive capacity could also be taxed if an emergency were to cause widespread impacts.

Vulnerable, less mobile populations

Facilities serving vulnerable, less mobile populations are sensitive largely because the people who live or regularly spend time in these facilities are themselves sensitive due to age (small children and the elderly), health, or other conditions and need assistance with daily, routine tasks. This causes additional challenges in responding to a flood event. For example, evacuating a senior housing facility could be complicated by large numbers of less mobile people who would need additional time, assistance, or equipment. Evacuating schools and childcare centers will require careful coordination so that there is adequate supervision of young people and safe locations identified where family members can be reunited.

Often, these types of facilities have some capacity to accommodate or adjust to emergency events such as flooding, as they generally have already prepared emergency response plans. Additional capacity can be gained by coordinating with emergency responders prior to emergencies to ensure that the location and number of people at each facility is known to emergency responders, keeping plans up to date, practicing evacuation procedures, having alternate, temporary shelter locations and meeting points pre-identified, and ensuring that there are upper floors within the facility where people or equipment could be housed during an emergency. Due to the sensitivity of these populations, a longer-term strategy may be to move these facilities out of areas threatened by sea level rise and storm events. While emergency preparedness and response is an adequate approach in the short-term, if these facilities or access to them were to confront frequent or severe flooding, such response strategies would likely be inadequate to protect populations that are as sensitive to disruption as those in vulnerable, less mobile populations.

Animal Facilities

Animal facilities share many of the same characteristics of the other facilities and services described above and have many of the same sensitivities, adaptive capacities, and need for advance preparedness and response planning. There are several categories that are often included when describing the vulnerabilities of animal facilities within communities. These categories include:

- Municipal and Non-Profit Animal Shelters
- Zoo, Wildlife and Marine Mammals
- Rescued Household Pets
- Evacuated Household Pets
- Lost and Abandoned Household Pets
- Livestock
- Research Animals
- Pet Shops, particularly those that sell exotic animals

Based on the data available regarding the types of facilities within the ART project area, there is one non-profit animal shelter located within the exposure zone. This animal shelter is located in the City of Alameda and is operated by the Friends of Alameda Animal Shelter (Figure 3). Data on the presence of pet shops, research animals, and livestock within the project area was not available. There are likely a number of household pets and possibly some backyard livestock within the project area.

Figure 3. Animal Shelter in the City of Alameda

Animal facilities are sensitive for a number of reasons. Animals are often extremely difficult to move and relocate for most households and facilities. Special equipment and personnel are often needed to safely move many animals and adequate re-location facilities are also necessary. For households with dogs and cats, even temporary displacement can be difficult, as hotels and rentals do not always allow pets. For those with horses, chickens, or other livestock, or exotic animals, temporary or permanent displacement poses additional challenges in looking for replacement housing. For these reasons, having pets can result in people making poor choices regarding evacuation, and make them more sensitive to hazards, if, for example, they choose to stay in order to take care of animals that are difficult to move and relocate.

Zoos, animal shelters, research facilities, and pet shops confront many of the same challenges as households regarding moving and relocating the animals in their care, except on a larger and more complex scale. There are more animals to address, there are often exotic and large species in their care, and they may not have the staff available for a large-scale evacuation or the facilities to relocate to temporarily or permanently once the animals have been removed from the hazard zone. In 2007, a series of wildfires caused the evacuation of most staff and some animals (cheetahs, condors, snakes) within the San Diego Wild Animal Park. However, through various adaptation measures to increase adaptive capacity in a fire zone, such as fire proof buildings on-site and significant fire-breaks around the perimeter of the zoo, it was possible for the animals to be evacuated to locations on-site.

Animal facilities, such as animal shelters and their staff, may confront a dual challenge during a hazard: the need to evacuate and relocate their own facility and the animals currently in their care, and the need to assist in the evacuation and re-location of household pets. Animal shelters are often operated with few financial resources, and paid staff are often not adequate for even the day-to-day operations of most shelters. When confronting response to a hazard that includes a change in operation, reduced access to the facility, or temporary relocation, paid staff will not be adequate to deal with most hazards and volunteers will be necessary to respond. Providing for both a response for the facility and service to the community will be a significant challenge, as it has when such hazards have occurred in other parts of the country. In such cases, neighboring facilities have assisted, temporary facilities have been set up and outside agencies and volunteers have provided significant assistance.

In addition to local agencies, there are several national non-profit and federal agencies that provide assistance and staff to local animal facilities. In recognition of the serious nature of the issue and the need for better coordination and preparedness, the Pets Evacuation and Transportation Standards Act was passed by the House of Representatives in 2006 in the aftermath of Katrina and signed into law. The law requires that states seeking Federal Emergency Management Agency (FEMA) assistance must accommodate pets and service animals in their plans for evacuating residents from hazards and recovery from that hazard.

Additionally, organizations such as the Humane Society of the United States and the United States Department of Agriculture provide trainings for communities and organizations on preparedness and response to hazards, and the Humane Society and other non-profit organizations has both paid staff and volunteers ready to assist in response.

In addition to the sensitivity of animals, households, and facilities, there is also a significant public health and safety risk if animals are not evacuated properly and become loose in the community. With respect to dogs and cats, the issues can include animal welfare and safety, predation and threats to wild and domestic species, biting and attacks, and the spread of disease. For exotic species, the danger to the environment and to the welfare of the animal may include an environment that is inhospitable for an animal who needs special care (heat lamps, treated water, special diet) or an animal that could create an imbalance in the native environment if allowed to hunt and reproduce.

Many of the sensitivities associated with animals and animal facilities within communities can be significantly reduced through developing preparedness and response plans for the pet and livestock owning households and animal facilities within each community. These plans must include strategies to avoid or minimize adverse impacts on animal welfare and public health and safety. The plans should include procedures for evacuating animals, including transportation, trained staff and volunteers and the proper tools (cages, leashes, tranquilizers if necessary); the potential sites for re-location, evacuation locations for household pets and livestock; and assistance in the recovery of the community's animal facilities. For the ART project area, the primary concerns will be household pets and some livestock, pet stores that have live animals in their care, and the Friends of Alameda Animal Shelter.

<u>Summary</u>

For most of the community services and facilities, a key to reducing sensitivity and increasing adaptive capacity is to plan ahead as neighborhoods and communities by developing preparedness and response strategies for the possible hazards that each community may confront, including earthquakes, storms and future climate hazards. This includes working together as part of a CERT or as an informal neighborhood collective, having household and neighborhood evacuation procedures and emergency supplies, and having certain members trained for the different roles that will be necessary, including moving the most vulnerable community members, first aid and assisting in animal evacuations. Although such preparedness and response strategies cannot eliminate sensitivity to hazards, these strategies can, in certain circumstances, significantly reduce this sensitivity and save lives.

In addition to developing preparedness and response strategies, the way that communities are designed and constructed can also reduce sensitivity and increase adaptive capacity. Building codes, construction materials, overlay zones, site design and other strategies can be developed to apply to areas and uses where exposure is likely and sensitivity is high.

Consequences

The potential consequences of sea level rise and storm events on the residents, employees, facilities, and services in the ART project area could be significant, not only for the communities in the study area but for the region. Due to the varied and diverse nature of the land uses, facilities, and services, and because a detailed understanding of consequences would require resources beyond those available to the current project, only a high-level discussion of consequences is provided. A full assessment of the potential magnitude of the consequences for the economy, society, environment, and governance structures that would occur if community land use, services, and facilities were affected by a climate impact will require a specific and detailed evaluation of multiple factors, such as the severity of the impact on revenues and opportunities for financing operations, maintenance, and capital improvements; the demographics of the individuals and neighborhoods affected; the land uses and facilities affected, the types of natural resources affected and the services and benefits they provide; the regulatory and decision-making processes; and the type, extent, and severity of the effects on public health, safety, and welfare.

Economy

In addition to the obvious economic consequences of damage to residential, commercial, and government property, exposure to flooding can have additional, far-reaching economic impacts. If workplaces are forced to close, it can mean losses for the companies affected, as well as lost wages for workers and lost tax revenue. The threat of frequent flooding could even drive businesses out of an area permanently. In many parts of the Bay Area, including the ART project area, business and industrial parks where large numbers of employees work are located near the shoreline. Exposure of these job sites could disrupt jobs for thousands of workers, and property and business owners could face high costs to repair and replace damaged buildings, specialized equipment, and other items exposed to floodwaters.

Closed schools and other facilities housing vulnerable populations could mean time off of work and associated lost wages for parents and caretakers, and if alternative housing has to be found for individuals such as those living in group homes or long-term care facilities, it could drain the budgets that fund those facilities' operations. Further, if long-term evacuation is necessary, individuals, families, and businesses could choose to re-locate permanently outside of the community, with associated economic consequences for neighborhoods, employers, and cities. Additionally, while proper preparation will ultimately reduce economic consequences in the event of an impact, in the short term the resources expended in preparing for an impact will have their own economic consequences as individuals, businesses, and agencies make trade-offs within limited budgets.

Society

As addressed in depth in the ART project Equity White Paper and the discussion of the sensitivity and adaptive capacity above, the consequences of flooding for residents vary depending on the characteristics of the populations exposed. For most residents, being exposed to flooding will be very disruptive and could result not only in temporary displacement, but also the loss of belongings and personal and financial information that is hard to replace (such as birth certificates, passports, and living wills), high costs to repair damage and replace items, and the disruption of neighborhoods and lives, including lost time at school and work. Permanent displacement would increase the consequences beyond the individual scale and result in neighborhood and community scale impacts, such as the loss of neighborhood relationships and services. The flooding of small businesses and places where people work, or loss of access to these locations, could result in the temporary or permanent shutdown of operations and associated loss of livelihoods. Facilities serving at-risk populations face unique challenges in safely and properly evacuating and / or serving the population that relies on them. In the face of a climate impact, this population may become further marginalized and have greater difficulty recovering.

Figure 4. Flooding in San Anselmo in 1982 and 2005 damaged many local businesses. Photos are from New Years Eve flood, 2005.

Chronicle / Deanne Fitzmaurice, F Chronicle / Deanne Fitzmaurice, File

After a flood subsides, cleanup can require an enormous community effort, involving time and resources from property owners, residents, private and public agencies and organizations, and volunteers (Figure 4). Residents and workers may be able to return to their homes and places of work, but unless buildings are properly dried and cleaned, there may be health risks. For example, mold is common in flooded buildings, and it poses a serious health risk, particularly for people with asthma and certain chronic health conditions.

If police and fire stations, or access to them, were to be flooded, their ability to respond to an emergency would be compromised, making communities more sensitive and less able to adapt to climate impacts. Likewise, hospitals and health clinics exposed to flooding may be unable to care for patients. If schools and childcare centers are flooded, in addition to the challenge of evacuating children safely, school may be canceled while buildings, equipment and supplies are restored, significantly affecting the education of the affected children and the community that schools provide, including the relationships with teachers and peers.

Figure 5. Thousands of refrigerators waiting to be crushed at the Old Gentilly landfill outside New Orleans. Photo credit: Ed Kashi. http://www.onearth.org/article/rough-burial

In the event that facilities that house vulnerable or at-risk populations, such as shelters and senior housing, need to be evacuated, it could create additional burdens for caretakers, whether family members, caseworkers, or professional staff. The exposure of jails could create security concerns, or even threaten the safety of those locked in cells if nobody is on site to evacuate them. There is one animal shelter in the ART project area, the Friends of Alameda Animal Shelter, and a number of households with pets, some with livestock, and possibly some pet stores, research facilities and interpretive centers that house animals. Without the proper preparedness and response for these households and facilities, animal welfare and public health and safety will be at risk.

<u>Environment</u>
It is difficult to evaluate the consequences of sea level rise and storm events on community land use, facilities, and services from an environmental perspective, since each of these facilities is so different in the role that it serves and its relationship to the environment. One environmental consequence of flood-damaged buildings is the enormous amount of debris that is released into the environment, as well as other, damaged material that has to be disposed of (Figure 5). In a severely damaged home, carpets, drywall and refrigerators, not to mention any damaged clothing, furniture, electronics, and other possessions, may have to be discarded. Depending on the overall community response and types of materials, these items could be recycled, taken to landfills, or discarded illegally, each with its own environmental impact.

Invasive species is another significant concern related to sea level and storm events, and floods and higher water can result in invasive species being introduced to sensitive habitats and introducing predation or competition with native species. Additionally, if animal facilities or households with pets or livestock are not properly evacuated, animals could escape and cause problems for wild species.

Another environmental consequence could occur if Bay water floods community facilities containing hazardous materials such as pharmaceuticals, or buildings housing other harmful substances. For example, some basic household items such as paint, garden pesticides or automobile oil are environmentally harmful if released into the Bay, adding to the pollutant load there.

<u>Governance</u>
The governance consequences are significant with respect to community land use, facilities, and services but they will also vary with the type of facility or portion of the community exposed to sea level rise and storm events. Each of the different categories of use and function within community land use, facilities, and services has its own governance structures, relevant regulations, and critical relationships that will have consequences on how sensitive that use and facility will be and what impacts that will have on the populations served by these facilities. For example, the redevelopment of certain areas will directly affect the number of people living and working in areas that may be exposed, and zoning laws will influence the sensitivity and adaptive capacity of new buildings and neighborhoods. The creation of disaster response plans will require the participation of many local agencies as well as individuals who need to be educated about the risks associated with sea level rise.

In order to better understand these relationships and the potential for governance to either increase or impair resilience, the ART project is currently evaluating governance and institutional arrangements for the project area. Once the evaluation is complete, it will better define the governance consequences associated with community land use, facilities, and services.

Key Findings

The population of the ART project area was nearly 800,000 in the year 2000, and over 300,000 people were employed in the area in 2011. While less than one percent of residents would be exposed to the daily high tide with 16 inches of sea level rise, over 15% would be exposed to the most extreme scenario of a storm event with wind waves with 55 inches of sea level rise. Individually, residents are sensitive to sea level rise and storm events, some to a greater degree than others depending upon age, health, income, vehicle ownership, pet ownership and other characteristics of these residents. Sea level rise and storm events can result in significant financial and personal hardships for residents. These include the loss of personal and financial information and belongings, the cost to repair or replace belongings and homes, temporary or permanent relocation, increased insurance costs, if insured, the permanent loss of belongings and residency if not insured, and dislocation from jobs, schools and other important community services and ties. For these reasons, residential neighborhoods are particularly sensitive to hazards, including sea level rise and storm events. Near term strategies to increase adaptive capacity include either informal or formal emergency preparedness and response on both an individual and a neighborhood scale, reducing the items and living spaces below sea level in basements, obtaining either owner or renter insurance for property and personal belongings, improving drainage at the neighborhood scale, and knowing the agencies, services and facilities that will be critical in responding to a hazard such as a storm event. When sea level rise or storm frequency increases past a certain point in certain neighborhoods, many of these sources of adaptive capacity may be overwhelmed and more significant considerations will be necessary.

Less than one percent of workers in the ART project area would be exposed to the daily high tide with 16 inches of sea level rise, but 22% would be exposed to the most extreme scenario of wind waves with 55 inches of sea level rise. Employees, employers, and small business owners are vulnerable to sea level rise and storm events and the ability for individual business owners to protect their property is limited. While there are short-term solutions such as telecommuting (for some types of employment) and temporary relocation is possible, these approaches are not practical in the long run. Employees, employers, and small business owners have some adaptive capacity – sandbags and pumps can keep some degree of flooding at bay for a short period of time, emergency preparedness and response strategies can minimize impact, drainage can be improved, buildings can be designed or retrofitted to reduce impacts, and valuable possessions can be kept on upper floors where possible. However, none of these strategies would likely be sufficient to deal with frequent flooding or sea level rise in the longer term and the impacts to the employment, businesses, and the economy could include the relocation of businesses out of the subregion, the elimination of jobs, increased insurance costs, and increased maintenance, repair, and replacement costs.

Some buildings are more sensitive than others based on the materials used to build them and whether they are built at or above grade. Repairing damaged buildings and replacing damaged belongings and equipment is costly and takes significant time. The total property value in the ART project area, depending on how it is valued, is estimated at 45 billion dollars (replacement costs) and 86.6 billion dollars (assessed value). The percentage of property value exposed to each sea level rise scenario is fairly similar across the two valuation methods, ranging from one percent exposed to the daily high tide with 16 inches of sea level rise, to approximately 23% exposed to wind waves with 55 inches of sea level rise. While replacement costs and assessed value do not have inherent characteristics that make property more or less vulnerable to sea level rise, the value at risk could affect how cities and individuals choose to protect various assets, which in turn could affect the vulnerability of the people who rely on them.

Each of the community facilities serves a different role and population. In the ART project area, there are 35 emergency response facilities: 19 fire stations, ten hospitals, and six police stations. Most of these are not exposed to sea level rise, but some facilities are quite sensitive, due to the role they play in serving and sometimes sheltering vulnerable populations, the presence of specialized and sensitive equipment, and the possibility that access roads will be flooded. However, due to the very nature of these facilities, they should have fairly high adaptive capacity because personnel should be well trained to handle emergencies, and, in the case of fire stations at least, some equipment such as pumps, may be on hand. While the impairment of an emergency response facility could have serious consequences for the community relying on that facility, the existence of mutual aid agreements across the county should help to reduce the impact for police and fire stations, provided those service personnel are not overwhelmed. Hospitals will be much more sensitive and vulnerable due to the needs of patients, the role played in emergency response, and the specialized and sensitive equipment contained in their facilities.

Just over 200 facilities serve at-risk populations, the majority of which are health care facilities (without on-site patients). None of these facilities are exposed to the daily high tide with 16 inches of sea level rise, and only one is exposed to storm event flooding. Fifteen are exposed to wind waves only. With 55 inches of sea level rise, only four are exposed to the daily high tide, 15 are exposed to storm event flooding, and an additional ten are exposed to wind waves, for a total of 25, or roughly ten percent, exposed to the most extreme scenario. These facilities are quite sensitive due to the population they serve – for example, a flooded homeless shelter dislocates people who likely have very little, if anything, to fall back on. Other facilities, such as jails, will be particularly challenging to evacuate because people residing there need special supervision. Therefore, while the exposure of these facilities over the entire ART project area is relatively low, they have high vulnerability because of their sensitivity.

There are over 650 facilities serving vulnerable, less mobile populations. While none of these facilities are exposed to the daily high tide with 16 inches of sea level rise, and only 13 are exposed to storm event flooding, 53 are exposed to storm event flooding with wind waves. Sixty-eight, approximately ten percent, of these facilities are exposed to the most extreme sea level rise scenario, storm event flooding and wind waves with 55 inches of sea level rise. These facilities are sensitive because many are full-time residences for vulnerable populations, such as seniors who may need more time to evacuate, and long-term care patients who are in fragile health. While schools and childcare facilities do not house children full-time, they nonetheless present evacuation challenges due to the care and supervision needed for young children. Adaptive capacity is also fairly low, since alternative locations for many of the people in the facilities are limited. Furthermore, there are some "clusters" of facilities – for example, senior housing in Oakland – which are exposed to sea level rise and would all need to be evacuated at once and could strain local resources. Therefore, although exposure is relatively low system-wide, these facilities have high vulnerability because of their sensitivity.

There is one animal shelter in the ART project area, which is exposed to all scenarios except for the daily high tide with 16 inches of sea level rise. It is also highly sensitive because of the difficulty of both evacuating and relocating the animals in their care in the event of flooding, and providing assistance to people who need to evacuate with their pets. Due to high exposure, high sensitivity, and low adaptive capacity because of the lack of redundancy, this facility is very vulnerable. In addition to the animal shelter, there are likely a large number of household pets, some livestock, several pet stores, and possibly some research facilities or interpretive centers that have animals in their care within the ART project area, but due to the availability of information, the locations and numbers are not known. These households and sites are all also highly sensitive due to the difficultly of evacuating and re-locating with animals and the potential for some of these animals to become loose in the community and pose a risk to the welfare of the animals and to public health and safety.

Chapter 6. Structural & Non-Structural Shorelines

The ART project area shoreline is a diverse mixture of built and natural features. The northern portion of the project area, along the shoreline of Emeryville, Oakland, Alameda and San Leandro, is fairly urbanized with a predominance of engineered shoreline structures (Figure 1). In contrast, the southern portion of the project area, along the shoreline of Hayward and Union City, is less urbanized with non-engineered structures, natural shorelines and wetlands situated between the Bay and the built environment.

To assess the vulnerability and risk of such a diverse and varied shoreline a simplified categorization approach was developed. This approach used publically available data (e.g., EcoAtalas, BAARI, NOAA ESI), aerial photo interpretation and best professional judgment to classify the outboard (i.e., bay edge) shoreline into five categories (Figure 2). The categories were defined based on the primary function and the ability to inhibit inland inundation. The five categories include three structural and two non-structural shoreline types:

Structural shorelines

- Engineered flood protection (e.g., levees and flood walls) – protect inland areas from inundation
- Engineered shoreline protection structures (e.g., revetments and bulkheads) – harden the shoreline to reduce erosion and prevent land loss
- Non-engineered berms – protect marshes and ponds from wave erosion and provide flood protection to inland development

Non-structural shorelines

- Natural, non-wetland shorelines (e.g., beaches) – dissipate wave energy and provide recreational and ecological habitat value
- Wetlands (e.g., tidal and managed marshes) – dissipate wave energy, improve water quality and provide ecological habitat value

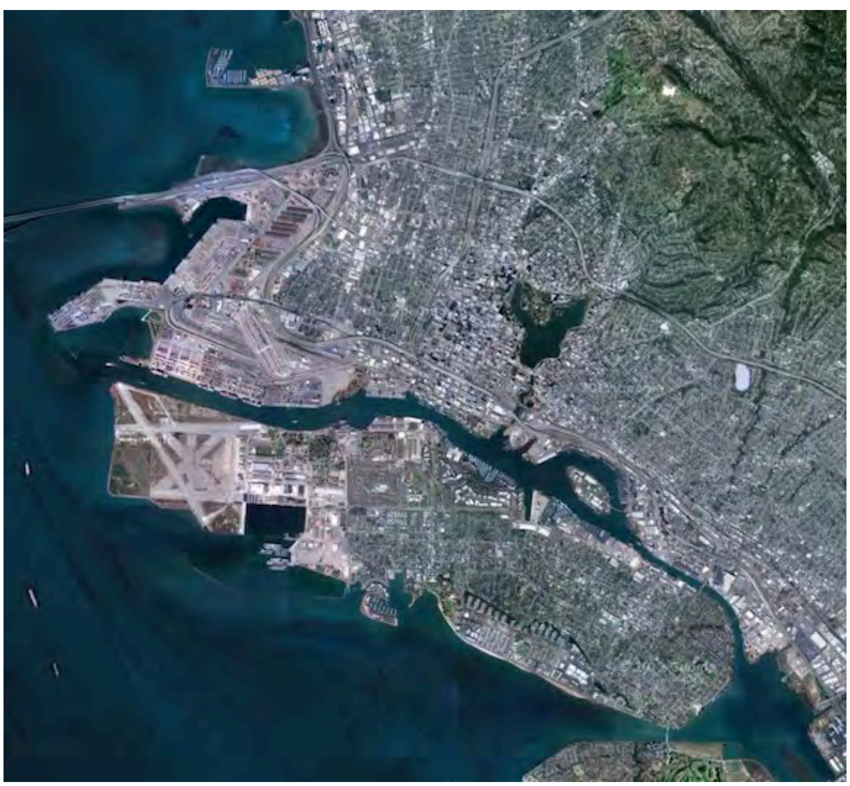


Figure 1. The northern project area is an urbanized shoreline that includes the Port of Oakland, EBMUD's main treatment plant, and the toll plaza for the San Francisco-Bay Bridge. Shoreline categories mapped onto northern ART project area include Engineered Shoreline Protection and Natural Shoreline/Beach.

An overview of the vulnerability of the three structural and one of the non-structural shoreline categories is provided below based on an evaluation conducted by a coastal engineering team for the Adapting to Rising Tides Transportation Vulnerability and Risk Assessment Pilot Project (AECOM, 2011); a similar overview of wetland shorelines is provided in Chapter 7. A more detailed assessment of the vulnerability and risk of individual shoreline assets will require specific information about the design, condition, ownership, current operation and maintenance and planned capital improvements of each asset or shoreline segment.

Figure 2. Shoreline categories in the ART project: 1) Engineered flood protection - levee with gate leading to LaRiviere Marsh (Source: Don Edwards San Francisco Bay National Wildlife Refuge); 2) Engineered shoreline protection - revetment along Emeryville's Marina Park; 3) Non-structural, natural non-wetland shoreline - Crown Beach (Source: Flickr Commons, Ingrid Taylor); and 4) Non-engineered berm in Eden Landing by Mallard, Hayward (Source: AECOM).

Exposure

Exposure is the extent to which an asset – such as an engineered flood protection structure, shoreline protection, or non-engineered berm – experiences a specific climate impact such as storm event flooding, tidal inundation, or elevated groundwater. The exposure of structural shoreline assets in the ART project area to two sea level rise projections and three Bay water levels was evaluated using a planning-level overtopping potential analysis.

The two sea level rise projections, 16 inches (40 cm) and 55 inches (140 cm), correlate approximately to mid- and end-of-century. These two sea level rise projections were coupled with three Bay water levels: the highest average daily high tide represented by mean higher high water (MHHW), hereafter "high tide" or "daily high tide"; the 100-year extreme water level, also known as the 100-year stillwater elevation (100-year SWEL), hereafter "100-year storm" or "storm event"; and the 100-year extreme water level coupled with wind-driven waves, hereafter "storm event with wind waves", or "wind waves." These water levels were selected because they represent a reasonable range of potential Bay conditions that will affect flooding and inundation along the shoreline.

Exposure of structural shoreline assets was determined using a potential overtopping analysis, which is more fully described in Chapter 2 and Appendix B. "Overtopping potential" refers to the condition where the water surface elevation exceeds the elevation of the shoreline feature that controls inland inundation. This analysis provides a high-level assessment of the structural shoreline assets that may not be of adequate height to prevent inland inundation by Bay waters under the various scenarios evaluated; it does not account for the physics of wave setup and runup, the condition of the shoreline asset, or the potential failure of the asset due to scour, undermining or a breach after the initial overtopping occurs

Results of the potential overtopping analysis are provided below for three representative shoreline areas, and are summarized for the project area as a whole in Chapter 2.

Sensitivity and Adaptive Capacity

The sensitivity and adaptive capacity of structural and non-structural natural shorelines in the ART project area were assessed for four potential climate impacts that could occur due to sea level rise and storm events:

- Permanent or frequent inundation by the daily high or extreme tide
- More frequent or intense floods
- Elevated groundwater levels and saltwater intrusion
- Potential for overtopping and erosion

Sensitivity is the degree to which an asset would be physically or functionally impaired if exposed to a climate impact. Adaptive capacity is the ability for an asset to accommodate or adjust to a climate impact and maintain or quickly resume its primary function. A high level summary of the sensitivity and adaptive capacity of the three structural and one non-structural shoreline categories (natural, non-wetland shoreline) is presented below.

Structural Shorelines

<u>Engineered flood protection</u>
The primary function of engineered flood protection structures, such as levees and flood walls, is to protect inland areas from inundation. They are designed to meet a specific level of protection with respect to freeboard[1], embankment protection, foundation stability, and settlement. Levees and flood walls are generally designed, at a minimum, to provide protection from the extreme coastal storm event (100-year stillwater elevation with wind waves).

[1] Freeboard is safety factor, expressed in feet above a flood level, which compensates for unknown factors such as wave action, bridge openings, and hydrological effects (for more information see www.fema.gov/plan/prevent/floodplain/nfipkeywords/freeboard.shtm).

The flood protection provided by levees and flood walls is sensitive to sea level rise. As sea level rises, flood levels will increase and wave conditions will change, potentially reducing the amount of freeboard provided and increasing the potential for overtopping and inland inundation. Without improvements to maintain minimum freeboard there will be a progressive reduction in the level of protection provided as sea level rises (Figure 3).

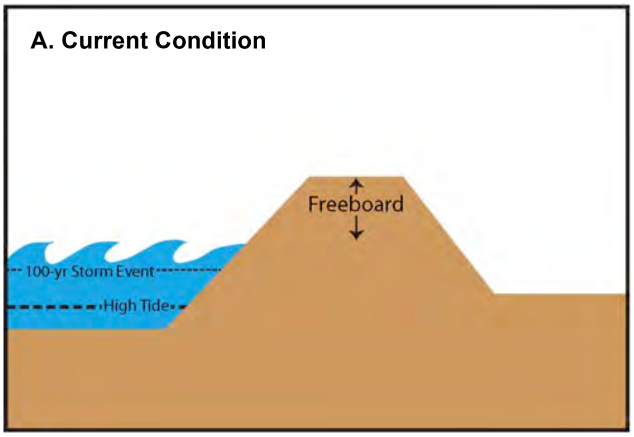
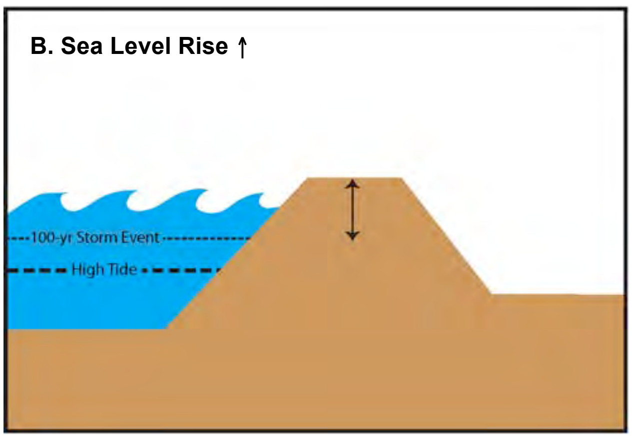
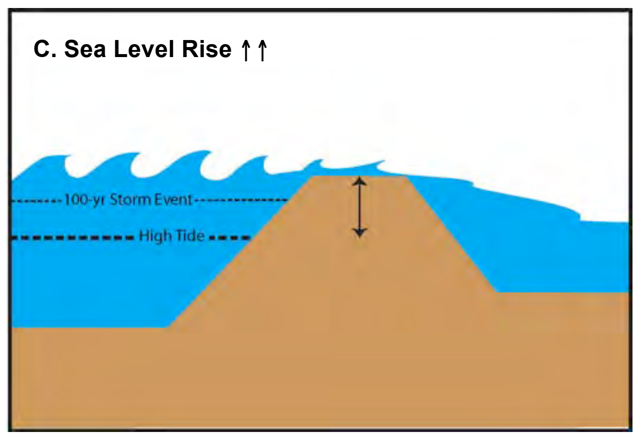


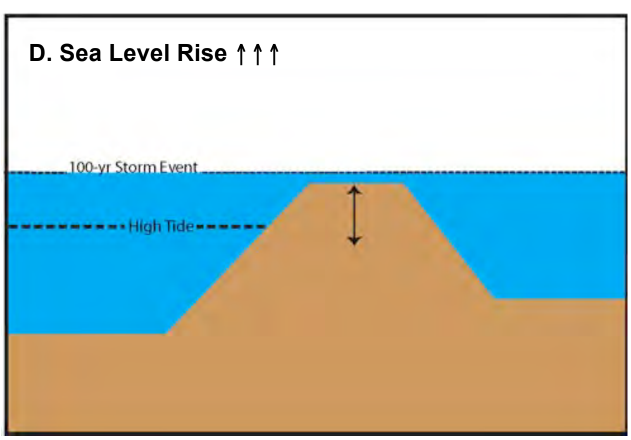
Figure 3. Engineered flood protection structures such as levees that currently have adequate freeboard will progressively lose their capacity to prevent flooding of inland areas as sea level rises unless they are improved or upgraded. Panel A represents current Bay water levels, while B - E show progressively higher Bay water levels as sea level rises.



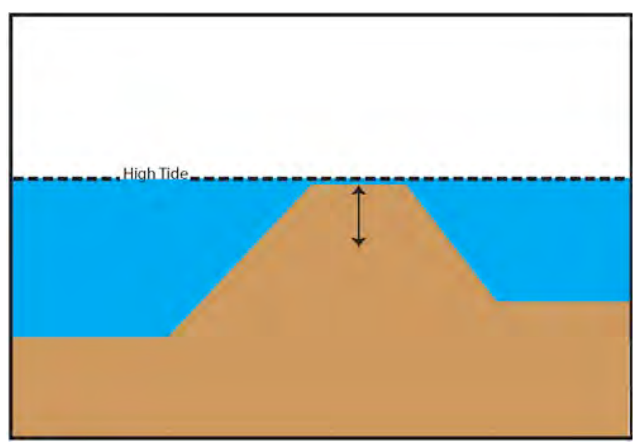
Structure does not have adequate minimum freeboard but is not overtopped.



Structure is overtopped by the 100-year storm event only if there are wind waves.



Structure routinely overtopped by the 100-year storm event regardless of wave condition.



Structure routinely overtopped at high tide.

The structural integrity of engineered flood protection structures is also sensitive to sea level rise. As sea level rises, wave conditions are also likely to change. Larger and more frequent storms could result in erosion of levee embankments or flood wall footings. Larger waves could cause overtopping of these structures, causing levee crest and backside erosion and possibly even failure. Inadequately maintained structures will have increased sensitivity to sea level rise.

Additionally, the entire ART project area has high seismic vulnerability and moderate to very high liquefaction susceptibility. Liquefaction during earthquakes could cause damage to structural shoreline assets, including levees and flood walls. Engineered flood protection structures have varying tolerances to seismic events, and elevated groundwater could increase the potential for liquefaction and lateral spreading, increasing the potential for damage during an earthquake.

The adaptive capacity of engineered flood protection structures will vary depending on a number of factors, including design, condition, routine maintenance, and the availability of funds for planning and operations.

Structures with the greatest adaptive capacity include:

- Those either located or designed in a manner that allows for improvement or upgrade to accommodate rising water levels and wave conditions. For example, levees that can be increased in height that have sufficient room to increase the overall footprint.
- Those with dedicated maintenance funding and permit authorizations allowing ongoing maintenance or improvements.
- Those that are already included in long-range capital improvement planning.

Structures with the least adaptive capacity include:

- Those that cannot be expanded due to physical or environmental constraints. If there is insufficient room to expand the levee footprint, improvements may necessitate a combination of approaches, e.g., adding a flood wall on top of a levee.
- Those without dedicated funds or without permit authorizations for ongoing maintenance or improvement.

Engineered shoreline protection

The primary function of engineered shoreline protection structures, such as revetments and bulkheads, is to harden the shoreline to reduce shoreline erosion and prevent land loss. The discussion below focuses on revetments since this is the most common engineered shoreline protection in the ART project area; bulkheads at the Port of Oakland are discussed in the Seaport assessment chapter[2].

In general, revetments consist of an armoring of erosion-resistant material (such as concrete or riprap) placed on an existing slope or an engineered embankment to protect the area from waves. Revetments are sensitive to degradation from erosion and overtopping depending on their design and condition. For example, armor is sized to remain in place given present wave action. Sea level rise may increase wave heights and velocities, resulting in mobilization of the armor layer. Additionally, overtopping could undermine the foundation and weaken the revetment. Lastly, if waves exceed design conditions, the toe could undercut and the entire structure could be compromised and potentially unravel.

[2] Bulkheads at the Port of Oakland are mostly unanchored (gravity) structures and therefore have some form of shoreline erosion protection beneath, e.g., riprap or stone. Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, November 2011, Chapter 2.

The adaptive capacity of revetments will depend on their size and location. Generally, revetments have moderate adaptive capacity since they can be upgraded over time to accommodate changing conditions. Improvements may include placing additional armoring or increasing the size of armor to cope with increasing currents and waves. It is also possible to increase the height of a revetment in response to higher high tides, extreme water levels or wave heights. If the size of the revetment is increased, the amount of toe protection may also need to be increased, which could be challenging if the structure is, for example, located in an environmentally sensitive area with high resource values. The maximum height of a revetment is limited by the height of the slope it is protecting; therefore it may be necessary to combine revetments with an engineered flood protection structure if additional protection is required.

<u>Non-engineered berms</u>

The primary function of non-engineered berms is to separate managed marshes and ponds from the Bay, although they also protect developed shorelines in some locations (Figure 4). These berms are essentially mounds of bay mud, which have not been engineered to meet specific design criteria. They provide some level of "ad hoc" flood protection to inland areas, especially if they are adjacent to expansive wetlands, which themselves help attenuate waves and reduce flooding. For example, in the southern portion of the project area, the expansive network of former and resorted salt ponds at Eden Landing and non-engineered earth berms provides a buffer between the Bay and inland developed areas. If the most outboard berms are overtopped, the ponds behind them, which are generally lower than the Bay, will fill. Because the ponds would provide flood storage, the next inland berm would not overtop unless the pond either reached capacity or there were wind waves that caused an additional rise in water level. If the system of pond and berms is adequate, Bay water levels could recede before the most inland berms are overtopped, protecting inland areas from inundation or flooding.

Figure 4. Non-engineered berm with riprap on outboard side (Source: Google Earth).

Non-engineered berms are sensitive to sea level rise and storm events, in particular to the erosive forces of currents and waves. Some berms are maintained on a regular schedule. Those that are adjacent to the Bay are maintained more often than those further inland as they exposed to more erosive tides, currents and waves. However, many berms are only maintained if erosion is observed or as failures occur. The ability to improve non-engineered berms to accommodate rising sea level and storm conditions is limited. Many berms cannot support the placement of additional material and therefore are already at a maximum height. In addition, the current maintenance practice in many locations is to excavate adjacent bay mud and place it on top of the berm. Once this supply of material is exhausted, suitable material will need to be imported. This will greatly affect that ability to cost-effectively maintain these structures, and will limit their ability to be modified to accommodate or adjust to sea level rise.

Non-Structural Shorelines

Natural, non-wetland shorelines
Natural non-wetland shorelines such as beaches can dissipate wave energy, protecting inland areas from large waves. They may also provide varying levels of flood protection depending on the extent of beach, topographic relief, and height of the associated dune system, if there is one.

In the ART project area, the most significant natural shoreline is the beach and sand dunes at the Robert M. Crown Memorial State Beach in Alameda[3]. Although the beach and dunes provide some protection from large waves, the beach is maintained with imported sand and engineered sand-retaining structures. Sea level rise and storm events could require more frequent replenishment or additional sand retention features at Crown Beach. Additionally, the dunes may need to be protected to help preserve the adjacent roadway. Shoreline interventions such as hardening, groins, or berms can interrupt the natural process of sediment transport, thereby increasing the sensitivity of the beach system to sea level rise and storm events.

Beach and dune complexes that are not naturally self-sustaining have low adaptive capacity, as they generally do not have the inherent ability to either accommodate or adjust to changes in water level, storm, and wave conditions without a significant amount of resources. In addition to the financial costs of such resources, there are also regulatory requirements that add to the complexity of either maintaining or improving the beach and dunes.

Representative Geographic Areas

To better understand both the vulnerability of the structural shorelines in the project area, and the potential risk to the inland areas and assets they protects, three representative geographic areas were selected for a more in-depth evaluation (Figure 5). Each of the three areas is comprised of a different combination of structural and non-structural shoreline assets and protects regionally significant services and facilities. The three areas selected include:

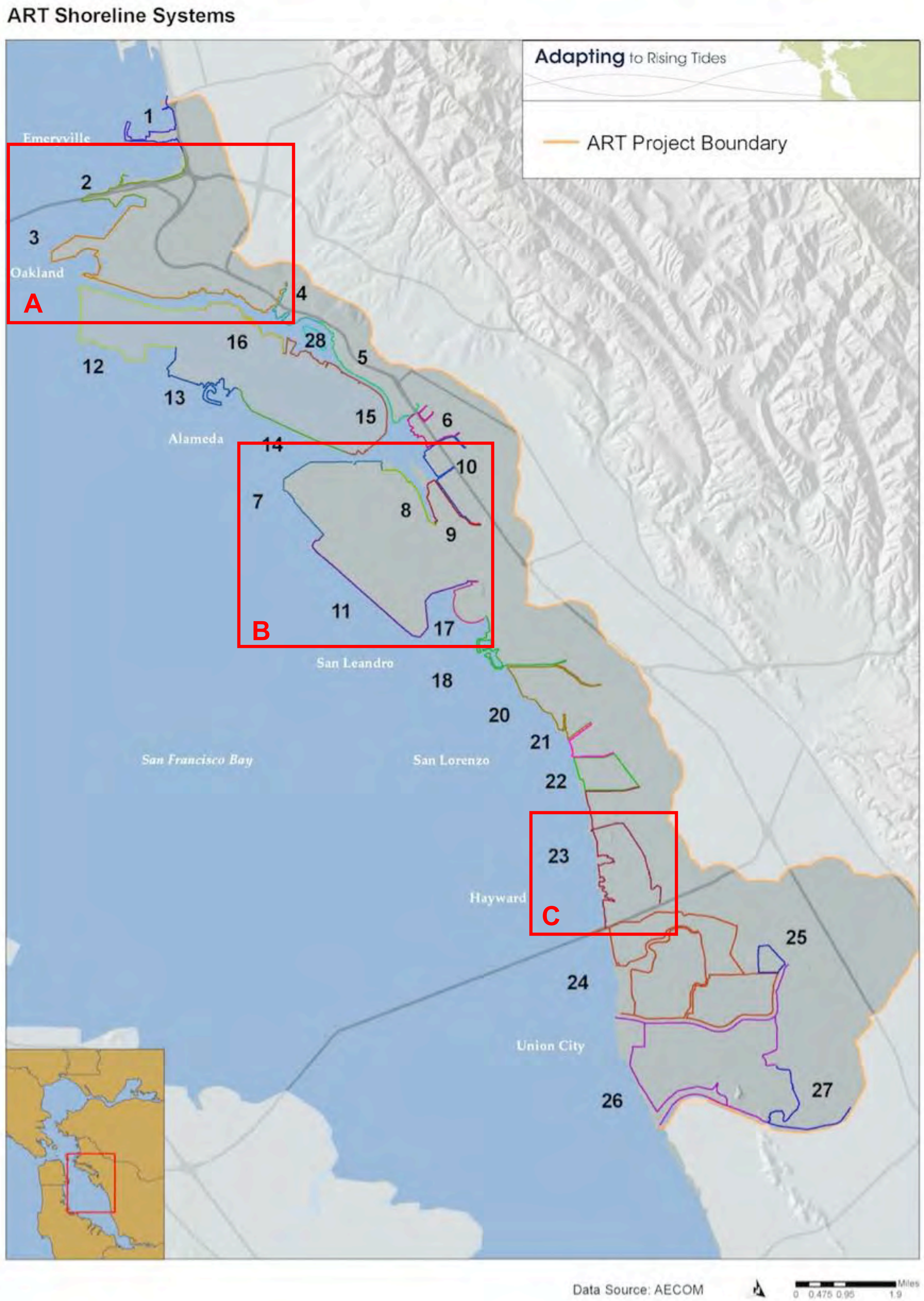
- San Francisco-Oakland Bay Bridge Peninsula and the Port of Oakland
- Bay Farm Island and the Oakland International Airport
- Hayward Area Shoreline

The assessment of the representative geographic areas also informs an understanding of the likelihood that the inland assets they protect will be exposed to inundation. In the following discussion, the exposure of each of the representative geographic areas, the vulnerability of the structural assets that comprises them, and the magnitude of the potential consequences on the inland areas is discussion. Where it was available, information is provided about the specific locations where exposure of the shoreline may occur and the types of vulnerable services and facilities nearby that could also be exposed.

Exposure of the three representative geographic areas was evaluated using the results of the overtopping potential analysis described in Chapter 2. Each of the areas is comprised of one or more shoreline system. Shoreline systems are contiguous reaches of structural and non-structural assets that together prevent inundation of inland areas. The systems were aligned to the feature that most likely prevents inland inundation, and therefore are mostly comprised of structural assets such as engineered flood protection, engineered shoreline protection and non-engineered earth berms, although in some locations the feature controlling inundation was a roadway or rail embankment. In areas where the shoreline was a natural feature, for example a tidal marsh or beach, the shoreline system was aligned landward at the feature controlling inland inundation (see Chapter 2 for a more complete description of the analysis).

[3] This park is evaluated in parks and recreation assessment chapter.

Figure 5. Three representative geographic areas include (A) the San Francisco-Oakland Bay Bridge Peninsula and the Port of Oakland; (B) Bay Farm Island and the Oakland International Airport; and (C) the Hayward Area Shoreline.



The potential overtopping analysis is summarized below for the shoreline systems that are within each of the three representative geographic areas. The overtopping potential results are presented as the percent of the total length overtopped, and the average and maximum depth of overtopping (see Table 1 and 2). These results are discussed in detail in the sections that follow[4].

Table 1. Percent of length overtopped for each system within the representative areas. Total length of each system provided as a reference.

System #	System Length (miles)	Percent of Length Overtopped					
		16" SLR			55" SLR		
		High Tide	Storm Event	Storm Event + Wind Waves	High Tide	Storm Event	Storm Event + Wind Waves
San Francisco-Oakland Bay Bridge Peninsula/Port of Oakland (13.9 total miles)							
2	4.4	4	45	73	54	72	99
3	9.5	1	12	45	18	41	100
Bay Farm Island/Oakland International Airport (10 total miles)							
7	3.5	0	6	64	21	66	94
8	1.6	0	74	100	94	100	100
11	4.9	0	0	54	1	50	100
Hayward Shoreline (7.6 total miles)							
23	7.6	10	30	98	68	98	100

Table 2. Average depth of overtopped (rounded to nearest half foot increment) for each shoreline system within the three representative areas.

System #	Average Depth of Overtopping					
	16" SLR			55" SLR		
	High Tide	Storm Event	Storm Event + Wind Waves	High Tide	Storm Event	Storm Event + Wind Waves
San Francisco-East Bay Bridge Peninsula/Port of Oakland						
2	1	1.5	4	2	4	6
3	1	1.5	2.5	2	2.5	4
Bay Farm Island/Oakland International Airport						
7	0	1	2.5	1	2	5
8	0	1	4	2	4	7
11	0	1.5	2	1	2	4
Hayward Shoreline						
23	2	2	3.5	2	3.5	7

[4] It is important to note that while the overtopping potential analysis summarized below can identify the location and depth of inundation at the shoreline it does not provide a complete picture of the consequences that an overtopping event will have on inland areas. Even if a short length of shoreline is overtopped, potentially large inland areas could be inundated. Additionally, if the overtopping results in a structural failure of a shoreline asset, larger areas could be inundated at deeper depths, resulting in greater consequences.

San Francisco-Oakland Bay Bridge Peninsula/Port of Oakland

The San Francisco-Oakland Bay Bridge Peninsula/Port of Oakland area extends from Temescal Creek in Emeryville though the Oakland Outer, Middle and Inner Harbors, to the west side of Lake Merritt Channel ending at 1st Avenue in Oakland. This shoreline area is protected by two shoreline systems, #2 and #3 (Figure 6).

- System #2 includes the Emeryville Crescent wetlands and riprap revetment engineered shoreline protection. This system protects the San Francisco-East Bay Bridge Peninsula, including the toll plaza.
- System #3 includes riprap revetment engineered shoreline protection as well as the bulkheads located at the Port of Oakland. This system protects the Port of Oakland, Jack London Square and Laney College/Lake Merritt BART station neighborhood.

Figure 6. The San Francisco-Oakland Bay Bridge Peninsula and Port of Oakland area is comprised of two shoreline systems, #2 in red and #3 in pink. (Source: Google Earth)

Together, these two systems protect the neighborhood of West Oakland and key regional infrastructure including Interstate 880 and 80, the Union Pacific Rail Yard, two BART stations and the East Bay Municipal Utility District (EBMUD) main wastewater treatment plant.

With 16 inches of sea level rise, less than 5% of either system #2 or #3 will potentially overtop at high tide (Table 1). However both systems will be significantly affected by storm events. During a storm event approximately half of system #2 could potentially be overtopped at depths averaging 1.5 feet (Figure 7). The majority of the overtopping will occur on the north side of system #2, in the vicinity of the Bay Bridge toll plaza. In comparison, 12% of system #3 could potentially be overtopped at an average depth of 1.5 feet during a storm event. Overtopping would increase to 45% and 2.5 feet if there were wind waves. The overtopping of system #3 will mostly occur at Oakland Middle Harbor along 7th street, at Jack London Square, and along the west side of the Lake Merritt Channel.

With 55 inches of sea level rise 50% of system #2 will overtop at high tide, and over 75%will overtop during a storm event. The average depth of overtopping will increase from 2 feet at high tide to 4 feet during a storm event. System #3 is less exposed, with 18% overtopping at high tide, and 41% during a storm event (Figure 8). Both systems will be entirely overtopped by a storm event with wind waves by average depths of 4 to 6 feet.

Figure 7. Approximately half of system #2 will overtop during a storm event with 16 inches of sea level rise (areas shown in blue). If there are wind waves during the storm the average depth of overtopping will increase from 1.5 to 4 feet. The overtopping generally occurs on the north side of the Bay Bridge toll plaza and along the Interstate 80 approach.

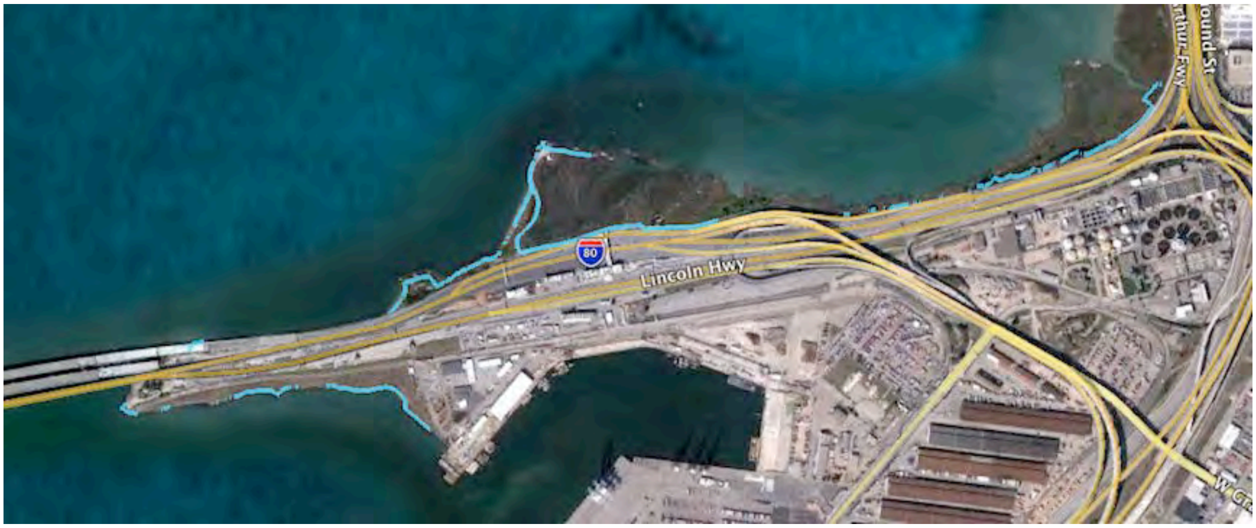


Figure 8. Almost half of system #3 will overtop during a storm event with 55 inches of sea level rise. In this case, Oakland Middle Harbor will overtop with 2 feet of inundation (areas shown in teal). If there are wind waves during the storm overtopping will occur along the entire system.

The San Francisco-Oakland Bay Bridge Peninsula/Port of Oakland area is mostly comprised of engineered shoreline protection, which can be sensitive to degradation from overtopping and erosion depending on the design and condition. Engineered shoreline protection does however have some adaptive capacity, because it can be upgraded or modified to accommodate increased water levels, currents and waves if the structure is not already at its maximum height. In addition, there are bulkheads at the Port of Oakland, which is fairly unique to the ART project shoreline. The bulkheads are mostly unanchored (gravity) structures with shoreline erosion protection beneath, e.g., riprap or stone. Also, critical infrastructure for Port operations is located beneath the bulkheads, for example electrical conduit for shore-side power. Therefore, while the bulkheads may not be sensitive it is possible that erosion protection and infrastructure beneath them could be adversely affected by sea level rise and storm events.

Overall, this representative geographic area is highly sensitive to storm events. System #2 which protects the Bay Bridge toll plaza is more exposed then system #3, and is likely to be more sensitive as it includes the Emeryville Crescent wetlands (see Chapter 7). The consequences of a failure in either system #2 or #3 will be very high, as they each protect regionally significant infrastructure, as well as the residential, commercial and industrial land uses within West Oakland (See Chapter 5).

<u>Bay Farm Island/Oakland International Airport</u>

The Bay Farm Island/Oakland International Airport area is comprised of three shoreline systems that protect Bay Farm Island and the Oakland International Airport (OAK), including (Figure 9).

- System #8 includes engineered flood protection structures (levees) and non-engineered earth berm. This system protects the eastern side of Bay Farm Island, including Shoreline Park along Doolittle Drive from Swan Way to Harbor Bay Parkway.
- System #7 is comprised of engineered flood protection structures (levees). This system protects the north side of Bay Farm Island, including Shoreline Park from Harbor Bay Parkway on Doolittle Drive to the OAK perimeter dike just past North Loop Road.
- System #11 is comprised of engineered flood protection structures (levees). This system protects OAK from North Loop Road along the north side of Airport Canal, to Davis Street. It also protects the Metropolitan Golf Links and San Leandro's Wastewater Treatment Plant.

Figure 9. The Bay Farm Island/Oakland International Airport shoreline area is comprised of three systems, #8 in purple, #7 in red, and #11 in orange. (Source: Google Earth)

With 16 inches of sea level rise none of the systems will be overtopped at high tide (Table 1). However, during storm events, 74% of system #8, which is one of the shortest systems in the ART project area, will be overtopped (Figure 10). In contrast 6% of system #7, which protects the northern portion of Bay Farm Island, will overtop, and none of system #11, the OAK perimeter dike, will overtop. Airport services and facilities could be exposed during a storm event with 16 inches of sea level rise from the overtopping of system #8 rather than from the airport's perimeter levee.

If there are wind waves during the storm event overtopping of system #8 increases to 100%, and average depths will increase from 1 foot to 4 feet (Table 2). For system #7, overtopping increases from 6% to 64%, and average depths will increase from 1 foot to 2.5 feet. The portion of system #7 potentially overtopped is along the northern end of Bay Farm Island, along Shoreline Park (Figure 11). This section of shoreline was categorized as a non-engineered earth berm because it is not heavily armored, and is not mapped as a levee/flood protection structure. This area of shoreline is therefore more sensitive to sea level rise and storm events

Figure 10. With 16 inches of sea level rise all of system #8 will overtop during a storm event with wind waves (areas shown in blue). This system, which is only 1.6 miles long, could lead to inundation at the airport well before the OAK perimeter dike is vulnerable.

Figure 11. With 16 inches of sea level rise more than half of system #7 will overtop during a storm event with wind waves (area shown in purple). Along Shoreline Park and the Bay Trail, overtopping depths will potentially be 2.5 feet on average. In addition, as sea level rises this section of shoreline will be exposed to erosion from wind-driven waves and will require additional protection.

than areas identified as engineered flood protection structures (e.g., levees). System #11, the OAK perimeter dike, will have more than half of its length overtopped during a storm event with wind waves with an average depth of 2 feet. This potential overtopping is located on the south side of the island along the Airport Canal (Figure 12).

With 55 inches of sea level rise all of system #8 is overtopped. Average depth of overtopping is 2 feet at high tide, 4 feet during a storm event, and 7 feet if there are wind waves. Only 20% of system #7 and 1% of system #11 are overtopped at high tide; however, this increases to over 50% during a storm event, and almost 100% if there are wind waves. The depth of overtopping within these two systems increases from 1 foot at high tide, to 2 feet during a storm event, to at least 4 feet if there are wind waves.

The Bay Farm Island/Oakland International Airport shoreline area is mostly comprised of engineered flood protection structures. However, the northern portion of Bay Farm Island within system #8 is protected by a non-engineered structure (Figure 13). Engineered flood protection is designed to protect inland areas from flooding, and is not as sensitive to overtopping and erosion (depending on the design and condition). Non-engineered structures are very sensitive to changing tides, currents and wave condition, and are likely to be adversely affected by sea level rise and storm events. Additionally, they have limited capacity to be easily, simply or in a low-cost manner improved to better protect inland areas.

Overall, this area is highly sensitive to storm events. System #8, which is a relatively small system in length, is sensitive to storm event overtopping. This system helps to protect regionally significant infrastructure including the services and facilities necessary for the operation of the airport. In addition, the portion of system #7 along northern Bay Farm Island that is non-engineered earth berm is also sensitive and plays a role in protecting the residences on Bay Farm Island and the northern portion of the airport. Lastly, there is a portion of system #11 along the Airport Canal that is sensitive to storm events. Failure of any one of these three systems could have significant consequences on the region, not only due to the loss of airport operations but also the loss of access to jobs, impacts on commercial, industrial and residential land uses, and potential disruption of utility infrastructure such as the San Leandro wastewater treatment plant.

Figure 12. With 16 inches of sea level rise, 54% of system #11 will potentially overtop during a storm event with wind waves to an average depth of 2 feet (area shown in purple). This potential overtopping is located on the south side of the island along the Airport Canal.

Figure 13. The northern portion of Bay Farm Island, from the Bay Farm Island Bridge to Aughinbaugh Way, is protected by a non-engineered earth berm structure, and is vulnerable storm events with sea level rise.

Hayward Regional Shoreline

The Hayward Regional Shoreline area extends from the south side of Sulphur Creek to the Hayward-San Mateo Bridge. It is protected by one shoreline system, #23 (Figure 14).

- System #23 is comprised of non-engineered berm along the bayshore, and engineered flood protection structures along Sulphur Creek and Depot Road. This system protects key industrial and commercial job centers on Depot and Cabot Roads, access to the Hayward-San Mateo Bridge, Hayward's Wastewater Treatment Plant, and the East Bay Dischargers Authority (EBDA) Hayward Effluent Pump Station.

Figure 14. The Hayward Regional Shoreline area is comprised of one system, #23 shown in orange below.

The Bay Trail is located on the bayshore levee that protects the Hayward Regional shoreline, including a closed landfill, four managed marshes including the Hayward Marsh, and for fully tidal marshes including Triangle, Cogswell and the HARD marsh (see Chapter 7). It also includes the levee along Depot Road, inboard of Hayward Wastewater Treatment Plant's out-of-service oxidation ponds and sludge drying beds, the inboard levee along Hayward Marsh, and the levee along the south side of Sulphur Creek.

With 16 inches of sea level rise at high tide, 10% of system #23 will be overtopped by 2 feet on average. During a storm event 30% of the system will be overtopped by 2 feet, and if there are wind waves almost the entire length of the system, 98%, will be overtopped by 3.5 feet (Table 1 and 2). The majority of the overtopping during a storm event is along the engineered flood protection structures on Depot Road, and along the bayshore non-engineered berms that protect the marsh systems (Figure 15).

Figure 15. With 16 inches of sea level rise, 30% of system #23 will overtop with an average depth of 2 feet during a storm event (areas shown in blue). The overtopping is mostly along Depot Road adjacent to industrial and commercial businesses.

With 55 inches of sea level rise, 68% of system #23 will be overtopped by an average of depth 2 feet at high tide. The majority of this overtopping is along the engineered flood protection structures on Sulphur

Figure 16. With 55 inches of sea level rise, almost 70% of system #23 will overtop with an average depth of 2 feet (area in dark blue). The majority of overtopping will occur along Sulphur Creek and Depot Road levees, and along the Bayshore non-engineered earth berms.

Creek and Depot Road, and along the bayshore non-engineered berms that protect the managed and fully tidal marsh systems (Figure 16). During a storm event nearly the entire system will be overtopped whether or not there are wind waves. The average depth of overtopping will, however, increase from 3.5 feet during a storm event to 7 feet during a storm with wind waves (Table 2).

The engineered flood protection structures along Suphur Creek and Depot Road may be sensitive to overtopping and erosion depending on their design and condition. In addition, the areas they protect include natural resource such as tidal and managed marshes, recreational access areas, and utility infrastructure. The opportunities to modify or improve the engineered flood protection systems to accommodate higher bay water levels, currents and waves may be limited by existing or potentially competing uses. The consequence of a failure of the Depot Road levee would be considerable as this segment of shoreline protects the Hayward wastewater treatment plant, and there is significant wastewater conveyance infrastructure owned by the East Bay Dischargers Authority (EBDA) between the out-of-service oxidation ponds and Depot Road.

The levees within the Hayward Regional Shoreline are maintained by East Bay Regional Parks are already affected by storm events. Not only are they sensitive to storm events, they have limited adaptive capacity as there are not enough resources to keep them maintained and there are limited opportunities as well as regulatory hurdles to making necessary improvements.

In addition to engineered flood protection structures, this area also includes a significant amount of non-engineered earth berms and some wetlands (e.g., Cogswell Marsh). Non-engineered berms, due to their design and construction, are sensitive to sea level rise and storm events and typically have limited capacity to be improved or modified. Non-engineered earth berms protect Hayward Marsh, a unique managed fresh and brackish marsh system that receives secondarily treated wastewater from Union Sanitary District. These berms are sensitive and have minimal adaptive capacity. Overtopping would lead to the degradation of these berms, compromising the function of the marsh. The failure of this portion of the shoreline would have significant economic and environmental consequences, and would require multi-jurisdictional, multi-agency coordination and collaboration that could be very challenging.

Consequences

Consequences are the magnitude of the economic, social, environmental, and governance effects if an impact occurs. Factors that inform magnitude include the severity of the impact on the asset in terms of operations, maintenance, and capital improvement costs, the size and demographics of the population affected, the types of natural resources affected, and the jurisdictional complexity to manage the asset.

The consequences of sea level rise and storm events on structural and non-structural shorelines will both be significant to the shoreline asset, and to the inland areas protected by that asset. The potential consequences on the aforementioned shoreline types are discussed below, the larger consequences to inland areas, including communities, facilities and services, are discussed elsewhere in this report.

Economy
There are significant costs associated with maintaining or improving structural shoreline assets. The repair and replacement of structural shorelines, where feasible, will require funding for design, permitting, materials, construction, and on-going maintenance. These costs will vary with the type and location of the asset, and access to adequate financing could be difficult for many of the public and private entities that own and maintain these shorelines.

Society
If the shoreline structures that protect inland areas from inundation erode, overtop, or fail, there will be significant consequences for communities, facilities and services. The consequences of the shoreline failing to protect inland assets are discussed in other chapters of this report, and are considered in the discussion of communities, facilities and services.

Environment
Natural non-wetland shorelines (beaches) and non-engineered berms offer both direct and indirect environmental value in promoting or supporting subtidal (e.g., eelgrass beds) and sandy beach habitat. These areas are also often the first line of defense against tides, currents and wind and wave erosion. The degradation and loss of these types of shorelines would threaten the species that rely on beaches and wetlands.

Governance
Shoreline assets in the ART project area are owned, maintained, financed and regulated by a complex system of public and private entities, including some of the following local, regional, state and federal agencies:

- Port of Oakland (shoreline protecting Oakland International Airport and the Seaport)
- Alameda County Flood Control and Water Conservation District (ACFCWCD) (shoreline throughout the ART project area)
- California Department of Transportation (shoreline protecting transportation assets such as the San Francisco-East Bay Bridge)
- U.S. Army Corps of Engineers (shoreline around navigable waters)

Specifically, in the southern portion of the ART project area, much of the shoreline is owned and maintained by East Bay Regional Parks District, Hayward Area Recreation and Park District, ACFCWCD, and the California Department of Fish and Game. Shoreline assets may also require coordination with agencies such as, but not limited to:

- San Francisco Bay Conservation and Development Commission
- San Francisco Bay Regional Water Quality Control Board
- California State Lands Commission

- U.S. Fish and Wildlife Service
- National Oceanic and Atmospheric Administration National Marine Fisheries Service

This complex mixture of ownership and regulatory authorities presents challenges in the logistics of effective and timely management of these assets in the face of climate change.

Key Findings

The representative shoreline areas illustrate the vulnerability and risk of not only the shoreline structures, but also the inland areas they protect. Much of the shoreline in the ART project area will overtop with 16 inches of sea level rise during a storm event, especially if coupled with wind waves. With 55 inches of sea level rise during a storm event the majority of the shoreline will overtop even in the absence of wind waves. The different structural shoreline categories have different sensitivities to sea level rise and storm events. For example:

- Engineered flood protection structures that are overtopped could suffer erosion of the crest and backside of levees and flood walls, thus weakening the structures and increasing the potential for failure.
- Engineered shoreline protection structures could be weakened, mobilizing the armor layer, eroding the foundation, and undermining the toe protection, thus decreasing the stability of the structure and increasing the potential for failure.
- Non-engineered berms are particularly sensitive to erosion and, given their non-engineered nature, have a limited range of possible height or stability improvements.

The adaptive capacity of these shorelines will vary depending on the type, design, location and ongoing operation and maintenance regime. Structures that have space to expand and be improved, have dedicated funding and are already maintained proactively, have the highest adaptive capacity. Natural non-wetland shorelines (beaches) that are not already self-sustaining have low adaptive capacity.

There are both direct and indirect consequences of sea level rise and storm event impacts on these shorelines. The direct impacts include the economic costs associated with maintaining or improving structural or non-structural shoreline assets. In addition, there are governance challenges in financing and coordinating maintenance or improvements since shorelines are owned, maintained, and regulated by private individuals and organizations as well as local, regional, state and federal agencies. The indirect impacts include the potential damages and loss of the communities, facilities and services that these shorelines protect. These consequences are detailed in the assessment of shoreline communities and assets elsewhere in this report.

References

Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project. November 2011. Prepared by AECOM and Arcadis for the San Francisco Bay Conservation and Development Commission, Metropolitan Transportation Commission and the California Department of Transportation. Available at http://www.mtc.ca.gov/news/current_topics/10-11/sea_level_rise.htm.

Chapter 7. Natural Shorelines

The shoreline of the ART project area is a diverse mix of built and natural features. To assess the vulnerability and risk of such a diverse and varied shoreline a simplified categorization approach was developed. This approach used publically available data (e.g., EcoAtalas, BAARI, NOAA ESI), aerial photo interpretation and best professional judgment to classify the outboard (i.e., bay edge) shoreline into five categories (AECOM, 2001). The categories were defined based on the primary function and the ability to inhibit inland inundation. The five categories include three structural and two non-structural shoreline types:

Structural shorelines

- Engineered flood protection (e.g., levees and flood walls) – protect inland areas from inundation
- Engineered shoreline protection structures (e.g., revetments and bulkheads) – harden the shoreline to reduce erosion and prevent land loss
- Non-engineered berms – protect marshes and ponds from wave erosion and provide flood protection to inland development

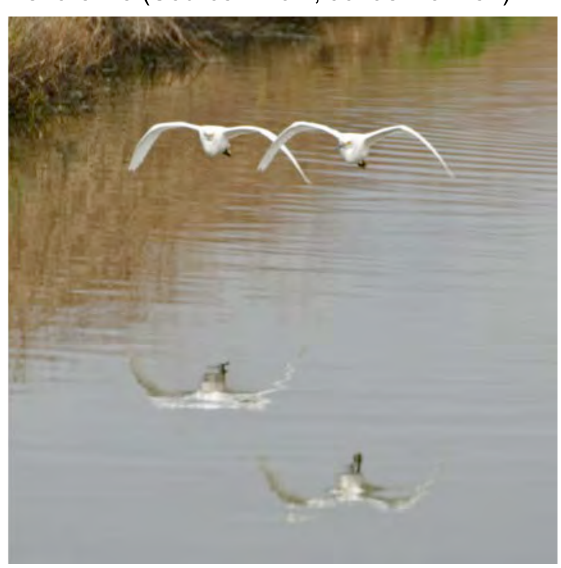
Non-structural shorelines

- Natural, non-wetland shorelines (e.g., beaches) – dissipate wave energy and provide recreational and ecological habitat value
- Wetlands (e.g., managed wetlands and tidal marsh) – dissipate wave energy, improve water quality and provide ecological habitat value

The vulnerability and risk of three structural and one non-structural shoreline category (natural, non-wetland areas, e.g. beaches) is discussed in Chapter 6. The vulnerability and risk of wetland shorelines is discussed separately in this Chapter because a different type of analysis is necessary when evaluating dynamic shoreline systems such as wetlands.

There are a number of different kinds of wetland systems in the ART project area. These include systems where the marsh edge is fully exposed to the bay (e.g., the Emeryville Crescent); systems that transition from tidal mudflat, to fringing marsh, to managed marsh (e.g., at the confluence of San Lorenzo Creek and the Bay); and systems that are a mosaic of tidal marsh, managed marshes and managed ponds (e.g., within the Hayward Regional Shoreline, Figure 1). These wetland systems are generally managed to preserve or restore ecosystem services such as wave energy dissipation, flood protection, water filtration and carbon sequestration. In addition they provide ecological benefits and habitat for a number of species of conservation concern.

Figure 1. Snowy Egrets at the Hayward shoreline (Source: Flickr, Jonas Flanken)



Rather than the approach used to assess the other asset categories in the ART project area, the vulnerability and risk of tidal marshes and managed marshes (Table 1) was evaluated in collaboration with PRBO Conservation Science (PRBO) using their online decision support tool

(PRBO tool)[1]. This approach was taken because wetlands are dynamic nearshore systems, and their response to changes in mean sea level rise will depend on a number of physical and biological factors including mineral sediment supply and organic matter accumulation. The sea level rise maps developed for the ART project that were used to evaluate the exposure of other assets do not account for potential changes in nearshore dynamic processes that are likely to occur with sea level rise (see Chapter 2 for more details on the mapping and analysis conducted). For example, neither organic matter accumulation nor sediment deposition and resuspension rates are considered even though these processes could alter the hydrodynamic or bathymetric condition in the Bay. Therefore, the PRBO tool was used to assess how tidal and managed marshes may change over the next 100 years in response to changes in mean sea level.

Table 1. Current size and habitat composition based on elevation relative to the daily high tide (MHHW) in NAVD88 of the twelve fully tidal and five managed marshes evaluated in the ART project area.

Location	Manager	Tidal Status[1]	Marsh Name	Current Acres[2]	Habitat composition (percentage by type) based on elevation relative to MHHW				
					Mudflat	Low Marsh	Mid Marsh	High Marsh	Upland
Eastshore State Park	EBRPD	Full	Emeryville Crescent	54	6	12	52	14	16
Martin Luther King Regional Shoreline	EBRPD	Full	Damon Marsh	9	5	12	76	3	4
		Full	Arrowhead Marsh	40	38	49	13	0	0
		Full	MLK - New Marsh	66	26	18	9	3	45
San Leandro	Citation Homes	Full	Citation Marsh	115	32	37	17	1	13
	EBRPD	Full	Robert's Landing	194	46	11	24	8	12
Hayward Regional Shoreline	EBRPD	Full	Oro Loma Marsh	274	33	41	16	5	5
	HARD	Managed	Frank's Tract	54	85	7	2	1	5
	HARD	Managed	West Winton	41	12	52	31	3	2
	EBRPD	Full	Triangle Marsh	8	28	41	25	1	4
	EBRPD	Full	Cogswell Marsh	195	6	7	35	36	17
	HARD	Full	HARD Marsh	79	18	33	32	3	14
	EBRPD	Managed	Hayward Marsh	212	1	47	37	2	12
	HARD	Managed	Oliver Salt Ponds	98	41	35	15	2	7
Eden Landing	CA DFG	Managed	Eden Landing Ecological Reserve (ELER)	2709	10	17	45	11	18
		Full	ELER Baumberg Tract	742	30	28	34	3	6
		Full	ELER Whales Tail, northern	278	4	2	4	22	68

[1] Tidal status indicates if the system is a fully tidal (full) or a managed marsh.
[2] Data from PRBO tool.

[1] San Francisco Bay Sea-Level Rise Website: A PRBO online decision support tool for managers, planners, conservation practitioners, and scientists (Hereafter, PRBO SLR tool). Available at: www.prbo.org/sfbayslr.

PRBO Tool

The PRBO tool is a publically available resource that evaluates through predictive modeling the vulnerability and resilience of tidal marshes throughout the entire San Francisco Bay region. The marsh accretion model and results that form the basis of the tool have been published in a peer-reviewed journal (Stralberg et al., 2011), and the conservation prioritization and tidal marsh bird and vegetation response to sea level rise are presented in a technical report to the California State Coastal Conservancy (Veloz et al., 2012).

The response of wetlands, and in particular tidal marshes, to sea level rise depends on a number of physical and biological factors, including the rate of sea level rise, the current elevation relative to the tidal frame, mineral sediment availability either from the Bay or nearby tributaries, and the rate of organic matter accumulation (Stralberg et al., 2011). The model depicts the future marsh condition by taking into account marsh accretion dynamics and incorporating spatial variation at a scale relevant for local decision-making. These factors are incorporated into the predictive modeling as follows:

- Sea Level Rise Rate: Two non-linear sea level rise rates - 0.52 meters (20.4 inches) or 1.65 meters (65 inches) over the next hundred years (2010 – 2110).
- Sediment Availability: Assumed low and high suspended sediment concentration (SSC) values that vary by biogeomorphic subregion[2] (0 to 300 milligrams per liter (mg/L))
- Organic Material: Assumed low and high organic matter (OM) accumulation rates that varies by biogeomorphic subregion (1 to 3 millimeter per year (mm/yr)).

The vulnerability and risk of wetlands in the ART project area was assessed based on the higher of the two sea level rise rates in combination with low/high sediment availability. The OM accumulation rate used was 1 mm/yr as the biogeographic subregions that include the ART project area are only represented by a single rate.

- The high rate of sea level rise, 1.65 m over 100 years, which corresponds to approximately 16 inches at 2050 and 55 inches at 2100.
- An assumed low SSC of 50 mg/L, and an assumed high SSC of either 100 or 150 mg/L (Table 2).

Table 2. Assumed low and high suspended sediment concentration (SSC) for wetlands in the ART project based on a biogeomorphic subregions identified by Stralberg et al. (2011).

<table>
<tr><th>Assumed Low SSC</th><th>Assumed High SSC</th><th colspan="2">Marsh Name</th></tr>
<tr><td rowspan="2">50 mg/L</td><td>100 mg/L</td><td colspan="2">Arrowhead Marsh
Damon Marsh
Emeryville Crescent
MLK - New Marsh
Robert’s Landing</td></tr>
<tr><td>150 mg/L</td><td>Citation Marsh
Oro Loma Marsh
Frank's Tract
West Winton
Triangle Marsh
Cogswell Marsh</td><td>HARD Marsh
Hayward Marsh
Oliver Salt Ponds
Eden Landing Ecological Reserve (ELER)
ELER Baumberg Tract
ELER Whales Tail (northern portion)</td></tr>
</table>

[2] The ART project area is within two of the 15 biogeographic subregions identified by Stralberg et al. 2011. Each subregion was assigned a high and low value for sediment supply and organic accumulation based on a combination of USGS monitoring reports, observed accretion rates from restored sites, and expert opinion in order to account for variability within the bay.

The PRBO model results for the high rate of sea level rise were evaluated for the assumed low and assumed high SSC for two time frames, mid-century (2050) and end-of-century (2090). While results from the PRBO model for these four cases provide the most realistic evaluation of sea level rise currently feasible, like any model, there are caveats and limitations. For example, the model does not include the influence of waves, which may cause erosion and marsh retreat along the bay edge and conversion of low marsh to mudflat. Consequently, projected habitat areas may be overestimates of future habitat potential, especially for low marsh. The assessment of vulnerability and risk using the PRBO model results, or any other modeled results, should be used in high-level planning exercises that will guide where future studies are needed to support robust decision making, and not as definitive results or answers (TNC and NOAA, 2011).

Sensitivity and Adaptive Capacity

The vulnerability of wetlands in the ART project area is assessed based on sensitivity and adaptive capacity, and not on an evaluation of exposure. The sea level rise mapping and analysis used to evaluate exposure of other assets in the subregion is not appropriate for tidal marshes or beaches, which are dynamic systems already within the tidal range that will likely exhibit a complex response to sea level rise (Figure 2).

Figure 2. Hayward shoreline near San Lorenzo Creek. (Source: Panoramio)

The PRBO tool was used to evaluate the sensitivity and adaptive capacity of twelve tidal marshes and five managed marshes in the ART project area. These two types of wetlands were considered separately because managed wetlands, which are shown in the PRBO tool as "diked," are areas that are or were at one time separated from the Bay. These areas remain under some level of management to control tidal and/or freshwater flows. Diked, managed wetlands tend to be at lower elevations than fully tidal wetlands due to subsidence, and they typically do not support coastal salt marsh vegetation found in fully tidal marshes. The PRBO tool uses the current elevation of these diked managed areas to predict the type of marsh habitat that could be supported if these areas were returned to tidal action. Each of these systems is managed differently (e.g., for flood protection or for ongoing, planned, or future restoration should resources become available). The tool, which was developed to evaluate future restoration potential, assumes the dikes are removed and wetlands fully revegetated at the start of the model run in 2010. Therefore, results for the managed marshes in the ART project areas should be interpreted in light of the potential to restore them to full tidal action in the future.

Historically, tidal marshes in the Bay have kept pace with low rates of sea level rise by accumulating mineral sediment and organic material (i.e., vertical accretion), and/or by migrating landward where the slope of the land is suitable and there are no inland barriers (i.e., upland transgression). However, as sea level rises, suspended sediment concentrations in the Bay decline (Schoellhamer, 2011), and with hardened shorelines and development adjacent to wetlands, there is less potential that tidal marshes will remain resilient to accelerating rates of sea level rise. While some wetland may persist, others will downshift in habitat type (e.g., change to a lower elevation habitat) and many could drown (e.g., become intertidal mudflat).

Sensitivity and adaptive capacity were evaluated for the fully tidal and managed marshes based on select information from the PRBO tool. To complete this analysis, first ART project staff identified the "footprint" of each tidal or managed marsh site based on a parcel data layer provided by Alameda County in combination with aerial photo interpretation. Then, for each site footprint PRBO staff summarized information from the PRBO tool including the current habitat composition; changes in future projected habitat based on elevation modeling; the conversion of uplands to wetlands based on elevation modeling, and changes in landscape conservation priority ranking based on Zonation, a spatial conservation planning tool (Stralberg et al., 2011, Veloz et al. 2012).

In general, tidal or managed marsh sites that either maintained their initial habitat composition or downshifted to lower elevation marsh habitats were assessed as having lower sensitivity to sea level rise. Marsh sites that transitioned to intertidal mudflat, especially if either by mid-century or under the assumed high suspended sediment supply scenario, were assessed as being highly sensitive. Additionally, sites that were able to maintain marsh habitat through upland transgression were assessed as having higher adaptive capacity, and those that either maintained or improved landscape conservation priority ranking were noted to have greater resilience as they would likely continue to provide critical functions such as maintaining biodiversity even in the face of sea level rise.

Tidal Marsh Sensitivity and Adaptive Capacity

Twelve fully tidal marshes in the ART project area were evaluated. These include one marsh in Eastshore State Park, three in Martin Luther King Regional Shoreline, two in San Leandro, four in the Hayward Regional Shoreline, and two in Eden Landing Ecological Reserve (Table 1).

<u>Vertical Accretion</u>
Tidal marshes are evaluated in the PRBO tool based on the potential for maintaining elevation relative to sea level rise through the accretion of mineral sediment and organic matter. Tidal marshes in the ART project area (as well as regionally) are sensitive to sediment availability. Under the low sediment scenario (50 mg/L), by 2050 five of the fully tidal marshes in the ART project area will downshift in habitat type (e.g., from mid to low marsh, or upland to mid marsh), two will persist as mid marsh, and five will transition to mudflat (Table 3). By 2090, all of the marshes are predicted to transition to mudflat.

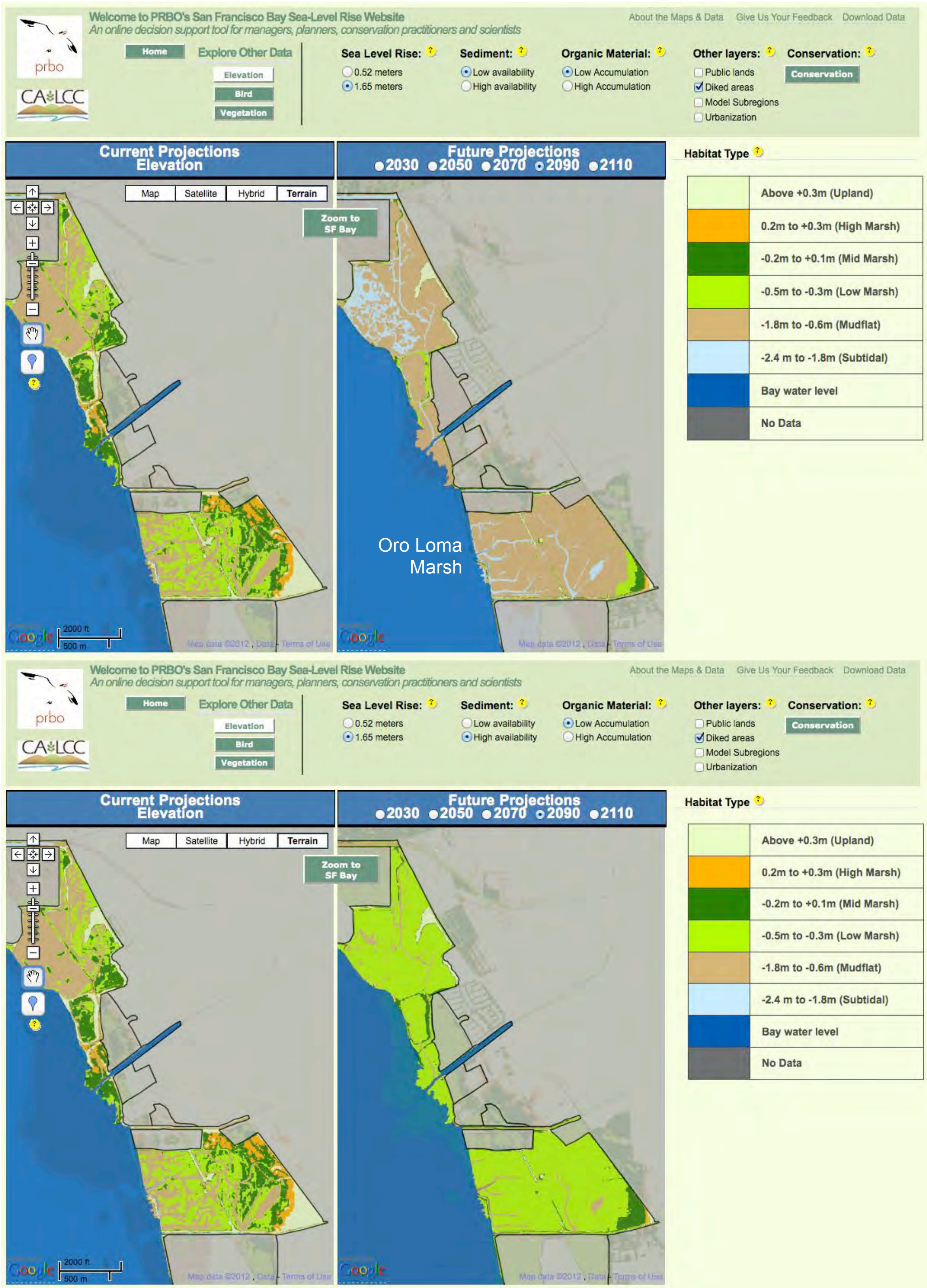
Under the high sediment scenario (either 100 or 150 mg/L), by 2050, all of the marshes except Arrowhead will persist as either mid or low marsh, and three will downshift in habitat type from upland to mid marsh or mid to low marsh. By 2090, all will persist as either mid or low marsh, except Arrowhead and Damon Marsh, both which downshift to mudflat (Table 3 and Figure 3).

Table 3. Predicted change in average habitat type based on modeled average elevation relative to MHHW NAVD88* for assumed high and low sediment scenarios in combination with a high rate of sea level rise and low rate of OM accumulation.

Marsh Name	Current (2010)	Low SSC		High SSC	
		2050	2090	2050	2090
Emeryville Crescent	Mid Marsh	Mid Marsh	Mudflat	Mid Marsh	Low Marsh
Damon Marsh	Mid Marsh	Low Marsh	Mudflat	Low Marsh	Mudflat
Arrowhead Marsh	Low Marsh	Mudflat	Mudflat	Mudflat	Mudflat
MLK - New Marsh	High	Mid Marsh	Mudflat	Mid Marsh	Low Marsh
Citation Marsh	Mid Marsh	Low Marsh	Mudflat	Mid Marsh	Low Marsh
Robert’s Landing	Low Marsh	Mudflat	Mudflat	Low Marsh	Low Marsh
Oro Loma Marsh	Low Marsh	Mudflat	Mudflat	Low Marsh	Low Marsh
Triangle Marsh	Low Marsh	Mudflat	Mudflat	Low Marsh	Low Marsh
Cogswell Marsh	Mid Marsh	Mid Marsh	Mudflat	Mid Marsh	Low Marsh
HARD Marsh	Mid Marsh	Low Marsh	Mudflat	Mid Marsh	Low Marsh
ELER Baumberg Tract	Low Marsh	Mudflat	Mudflat	Low Marsh	Low Marsh
ELER Whale’s Tail**	Upland	Mid Marsh	Mudflat	Mid Marsh	Low Marsh

*Elevation based on LIDAR elevations with +/- 2 – 3 cm vertical accuracy.
**The current habitat type at ELER Whale’s Tail is identified in the PRBO tool as “upland” which is not strictly correct. This error is due to inaccuracies in the LIDAR for this site that was used to develop the predicted current and future habitat types.

Figure 3. By 2090, if sediment availability is at the assumed low level, most of Oro Loma Marsh will become mudflat, and the small portion of high marsh and uplands in the southeast corner of the system will downshift to low and mid marsh (above). If sediment availability is high, the majority of the system will persist as low marsh, and high marsh and uplands will downshift to mostly mid marsh (below).



Upland Transgression

The capacity for upland transgression is evaluated in the PRBO tool as the potential for wetlands to expand into adjacent natural, not diked, upland areas. This is expressed as the acres of uplands converted to wetlands (i.e., low marsh, mid marsh and high marsh). For this analysis only uplands within the marsh site (identified as described above) were considered.

The total amount of uplands available for conversion across the twelve tidal marshes evaluated ranges from none (e.g., Arrowhead Marsh) to 190.6 acres (e.g., ELER Whale's Tail, Table 4). Under the low sediment scenario, by 2050 only one marsh, ELER Whale's Tail, is predicted to convert most of the available uplands, while two marshes, Damon and Robert's Landing, are predicted to convert more than half of the available uplands. There is no difference in the amount of uplands converted by 2050 between the assumed high and low sediment scenarios (Table 4). This is because conversion is limited by the availability of uplands at an elevation relative to sea level that will support marsh habitat rather than by sediment availability.

By 2090, most of the marshes will have converted half or more of the available uplands, with two exceptions, the Emeryville Crescent and Citation Marsh. The upland areas adjacent to these two sites are not at a suitable elevation to support marsh habitat (e.g., along the embankment of Powel Street along the north edge of the Crescent). Sediment availability is predicted to affect the amount of uplands converted to wetlands by 2090, with slightly more conversion occurring with a high sediment supply (Table 4). For example, Damon Marsh, Triangle Marsh and ELER Whale's Tail convert 100 percent of the upland area to wetlands under the high sediment scenario. In addition to the amount of uplands converted, sediment availability also determines the type of habitat the upland coverts to, and whether the converted uplands can persist as wetlands or will downshift to mudflat.

Table 4. Predicted acres of uplands converted to wetlands based on modeled average elevation relative to MHHW NAVD88 for assumed high and low sediment scenarios in combination with a high rate of sea level rise and low rate of OM accumulation. The data below constrains the uplands to adjacent natural, not diked areas within the identified marsh site footprint.

Marsh Name	Current Upland Acres (2010)	Percent Uplands Converted			
		Low SSC		High SSC	
		2050	2090	2050	2090
Emeryville Crescent	8.5	27	36	27	47
Damon Marsh	0.3	66	77	66	100
Arrowhead Marsh	0.0	--	--	--	--
MLK - New Marsh	29.5	13	80	13	84
Citation Marsh	14.5	11	32	11	35
Robert's Landing	22.5	55	73	55	88
Oro Loma Marsh	12.7	36	59	36	76
Triangle Marsh	0.3	16	94	16	100
Cogswell Marsh	32.3	45	62	45	86
HARD Marsh	11.2	39	85	39	96
ELER Baumberg Tract	45.6	43	78	43	90
ELER Whale's Tail	190.6	97	NA	97	100

For many of the tidal marshes evaluated, there is minimal opportunity for upland transgression due to existing development patterns. Damon Marsh, for example, is a small mid marsh dominated system that is constrained by the Interstate 880 corridor and existing land uses, including recreational and commercial facilities (Figure 4). Within the marsh site there are only 0.3 acres of uplands available, and most will convert to wetland as sea level rises. Further landward migration would require changes in the existing adjacent land uses, and would ultimately be constrained by I-880.

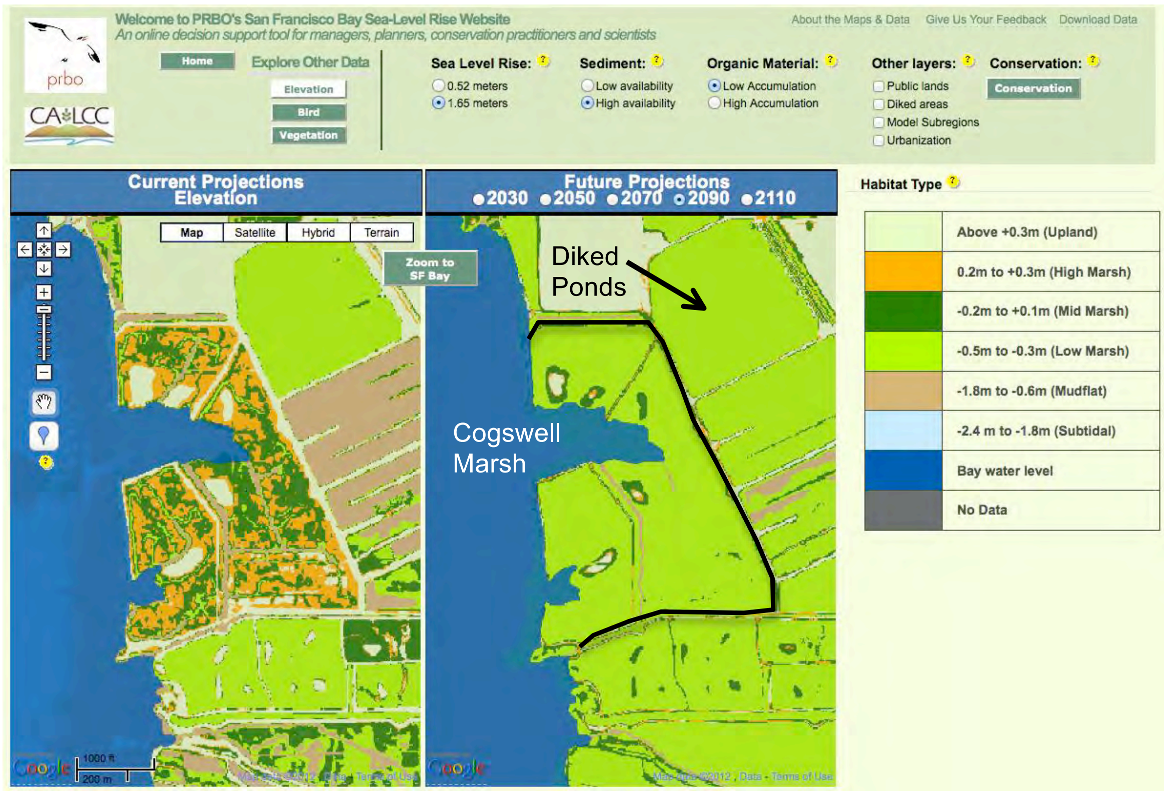
Figure 4. Migration of Damon Marsh would require changes in existing land uses, and would ultimately be constrained by the I-880 corridor. (Source: Google Maps)

In the southern portion of the project area where the Bay shoreline is less developed and the marshes are less constrained, many wetlands are adjacent to levees and dikes, and therefore the uplands are currently unavailable for transgression. For example, Cogswell Marsh is a mid and high marsh dominated system within the Hayward Regional Shoreline (Figure 5 and Table 3). The marsh adjoins some uplands of suitable elevation (32.3 acres) that could be converted to wetlands. Almost half of the uplands (14 acres) are predicted be converted to mid marsh by 2050. By 2090, 62 to 86% of the uplands (20 to 28 acres) are predicted to convert depending on sediment availability (Table 4).

Figure 5. Migration of Cogswell Marsh would require removal of dikes protecting the Hayward out-of-service oxidation ponds, and would ultimately be constrained by industrial land uses. (Source: Google Maps)

Further migration of the Cogswell Marsh is currently constrained by the levees that protect the City of Hayward's out-of-service wastewater oxidation ponds. Using the viewer function of the PRBO tool, rather than the data extracted in Table 4, it is possible to observe that if the levees were removed and the marsh was allowed to migrate landward, with low sediment availability (e.g., 50 mg/L) the ponds could convert to mudflat, whereas with a high sediment (e.g., 150 mg/L) the ponds could convert to low marsh (Figure 6). Ultimately, the landward migration of Cogswell Marsh will be constrained by exiting land uses, including Hayward's wastewater treatment plant and a number of industrial and commercial facilities.

Figure 6. By 2090, converted uplands at Cogswell Marsh are predicted to be a mixture of low and mid marsh if sediment availability is high in combination with a high rate of sea level rise and low rate of OM accumulation. Although small areas of uplands will remain, further landward migration could require the removal of dikes that protect the adjacent out-of-service wastewater oxidation ponds.



<u>Landscape Conservation Priority Ranking</u>

The current and predicted future habitat value of the fully tidal marshes in the ART project area was evaluated using the PRBO tool's landscape conservation priority ranking. The rankings are based on an analysis using Zonation, a spatial conservation planning software tool that takes into account the habitat value for multiple bird species under a combination of sediment availability and sea level rise rates to create a hierarchical prioritization of the landscape (Veloz et al., 2012). The conservation priority is based on current and future marsh conditions and informs whether tidal marsh habitat is resilient to sea level rise, i.e., habitat quality will remain high enough to support tidal marsh bird species.

The landscape conservation priority rankings are based on the predicted density of five bird species[3] for six time periods (2010, 2030, 2050, 2070, 2090 and 2110) for the combination of low and high sea level rise and low and high SSC rates. In addition, the analysis assumed that all dikes had been removed. This "no dike" assumption allows undeveloped natural areas that are not currently exposed to full tidal action to become tidal in the model, and therefore become a source of habitat for tidal marsh bird species.

While the two sea level rise and two sediment availability rates were used in combination with all time periods to determine the future conservation priority, the model down-weighted areas

[3] Predicted bird abundance was evaluated for Black Rail, Clapper Rail, Marsh Wren, Common Yellowthroat, and Song Sparrow.

if there was high uncertainty in the predicted densities of bird species. The results are therefore more strongly driven by the near-term (2010 to 2050), where there is less uncertainty, rather than the longer-term (2070 to 2100) future condition, where uncertainty is much higher. In addition, areas with consistent high bird species density across scenarios are ranked higher by Zonation, resulting in a more robust prioritization that is less sensitive to the uncertainty in future conditions.

In the PRBO tool, conservation priorities are divided into six categories[4], with a higher conservation priority rank indicating a greater potential to support tidal marsh birds. In the ART project area, the average conservation priority rank ranges fall within the first four categories (Table 5). All marshes except one (MLK-New Marsh) increase in conservation priority rank in the future scenario, suggesting that the tidal marsh function of providing habitat for the bird species evaluated is resilient to sea level rise, at least in the near-term.

Table 5. Current and future conservation priority rank for the fully tidal marsh systems in the ART project area (Very low = 0-0.30; Low = 0.31-0.5; Medium low = 0.51-0.75; Medium high = 0.76 - 0.90).

	Conservation Priority Rank	
Marsh Name	**Current**	**Future**
Emeryville Crescent	Low	Medium Low
Damon Marsh	Low	Medium High
Arrowhead Marsh	Low	Medium High
MLK - New Marsh	Low	Low
Citation Marsh	Very Low	Medium Low
Robert's Landing	Very Low	Medium Low
Oro Loma Marsh	Very Low	Low
Triangle Marsh	Very Low	Low
Cogswell Marsh	Very Low	Low
HARD Marsh	Very Low	Low
ELER Baumberg Tract	Very Low	Low
ELER Whale's Tail	Very Low	Low

Representative Tidal Marsh Systems

To understand how the physical and biological factors evaluated using the PRBO tool can inform the sensitivity and adaptive capacity of specific tidal marshes, two representative systems are discussed in greater detail below. The discussion also incorporates input provided by resource managers who have intimate knowledge of the sites. Together, information from the PRBO tool and best professional judgment provides insight as to the vulnerability and risk these marshes may face as sea level rises.

Emeryville Crescent

The tidal marsh at the Emeryville Crescent is owned by the State of California and managed by the East Bay Regional Park District (EBRPD). It is located between the Emeryville Peninsula (Powell Street), Interstate 80, and the San Francisco-Oakland Bay Bridge in Eastshore State Park (Figure 7). The marsh sits at the mouth of Temescal Creek, and is comprised of coastal salt marsh habitat, a few small natural sand beach formations, and intertidal mudflats that serve as foraging areas for shorebirds.

[4] Conservation priority ranking are divided into six categories: 0.00-0.30; 0.31-0.50; 0.51-0.75; 0.76-.090; 0.91-0.95; and 0.96-1.00

The marsh is currently a mid marsh dominated system with some low and high marsh, and an upland edge along Powell Street to the north (Table 1). The system is predicted to persist as mid marsh until at least 2050 (Table 2); however, if sediment supply is low there will be more mudflat, and if supply is high more mid marsh. By 2090, much of the marsh will transition to mudflat if sediment supply is low, and low marsh if supply is high.

Currently, inundation at high tide can displace the birds and wildlife using the marsh, and can leave behind a wrack line of trash and debris. More frequent or permanent tidal inundation due to sea level rise will exacerbate this situation, forcing birds and wildlife to forage and nest closer to Powell Street and Interstate 80, potentially reducing nest success. Additionally, the small sand beach areas and intertidal mudflat shore bird foraging areas could be reduced or eliminated as more areas in the marsh are inundated for longer periods of time.

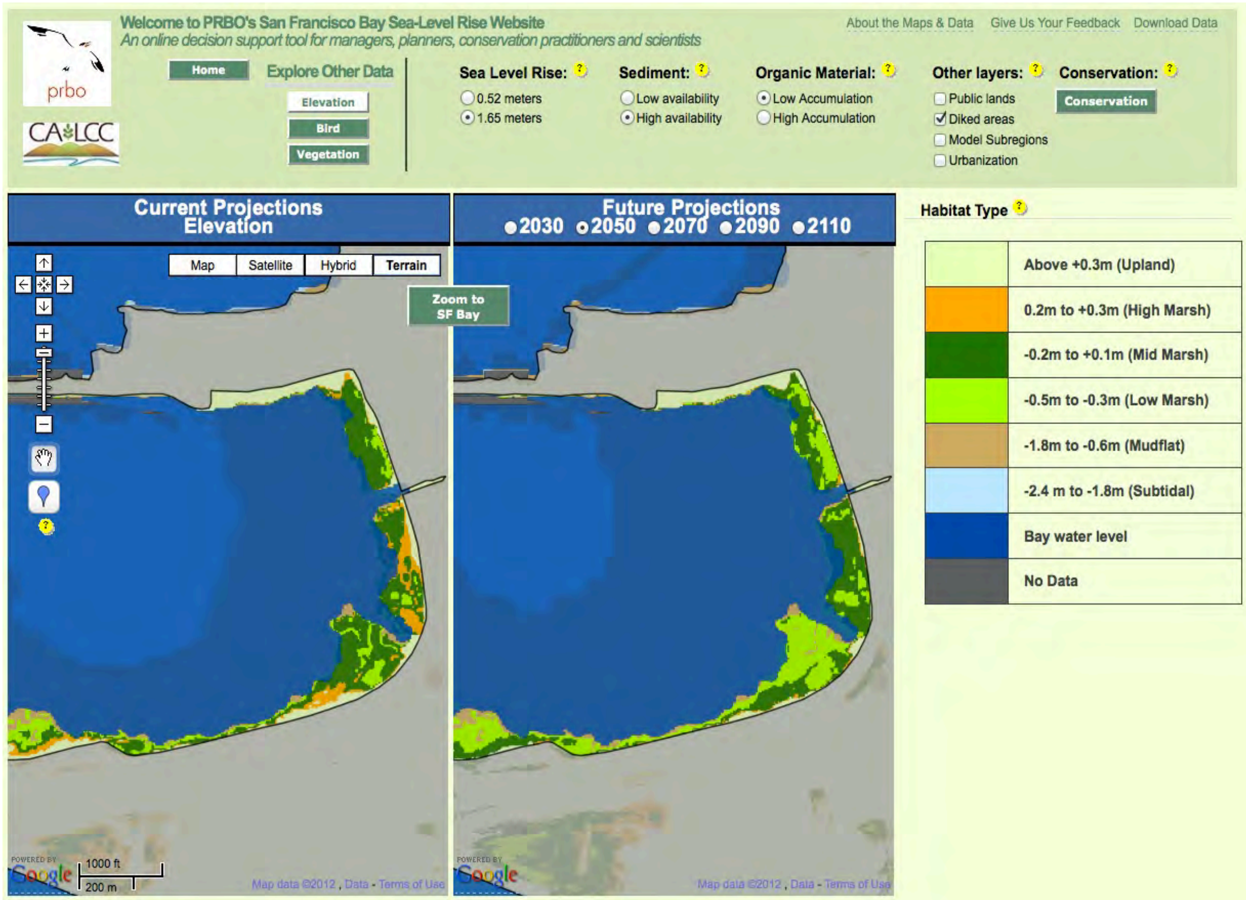
Figure 7. Emeryville Crescent is where Temescal Creek joins the Bay. The marsh is constrained by I-80 to the east and south, and Powell Street to the north. (Source: Google Maps)

Storm event flooding may have the greatest likelihood of causing damage to the upland area north of the marsh adjoining Powell Street. This area, which is partially protected by a loose mixture of broken concrete, metal slag and asphalt, is currently eroding. In addition, the low-lying upland areas adjacent to Powell Street currently flood during wet weather. Storm events could increase the potential for continued shoreline erosion, causing loss of adjacent upland habitat in areas already impacted by either high or extreme tides.

The Emeryville Crescent marsh has limited adaptive capacity. While there are some upland areas that could convert to wetlands (2 to 4 acres, 27 to 47 percent of the 8.5 acres available, see Table 4), much of these uplands are located along the Powell Street the embankment, and are not of appropriate elevation to support future marsh habitat. Further upland transgression is restricted by the I-80 corridor, development that surrounds this system, and ongoing management practices to protect the shoreline from erosion (Figure 8).

Improving the resilience of this marsh to sea level rise or storm events would likely be costly; however, it is a well-known natural shoreline area with an engaged public that could support its protection. This marsh is located adjacent to the San Francisco-Oakland Bay Bridge and toll plaza, a regionally significant transportation asset that will likely need to be protected. Holistic solutions for this area will need to consider potential impacts and opportunities for mutual benefits to both the built and the natural environment, including the capacity for the tidal marsh system to reduce inland flooding and shoreline erosion.

Figure 8. Predicted change in marsh habitat based on modeled average elevation relative to MHHW NAVD88 at the Emeryville Crescent by 2050 under a high rate of sea level rise, low rate of OM accumulation, and high sediment availability. Areas that are currently "diked" are shown in grey.



<u>Oro Loma Marsh</u>

Oro Loma Marsh is a 364-acre restored salt pond at the northern end of the EBRPD managed Hayward Regional Shoreline. The marsh is located in a fairly well developed portion of the ART project shoreline south and west of San Lorenzo (Figure 9). Despite being surrounded by levees, it is a fully tidal marsh, with Bockman Channel to the north, Sulfur Creek to the south, the Southern Pacific Railroad right-of-way to the east, and the Bay Trail on the bayside levee to the west. In addition to providing shoreline recreational access, this segment of the Bay Trail serves as emergency vehicle access from Grant Avenue in San Lorenzo, if, for example, the railroad is under repair or in case of a derailment. Lastly, there is a utility corridor that transects the middle of the marsh that includes a PG&E distribution and transmission line, an abandoned Shell Oil gas line, and the East Bay Dischargers (EBDA) effluent pipeline.

Because the marsh is a restored salt pond, it is at a fairly low elevation relative to MHHW and is dominated by low marsh and mudflat. Under the low sediment scenario, most of the marsh will downshift to mudflat by 2050 and will persist as mudflat by 2090. However, some marsh habitat in the portions of the system farthest from the Bay will remain (see Figure 10). Under the high sediment scenario, the marsh is predicted to persist as low marsh (Table 3).

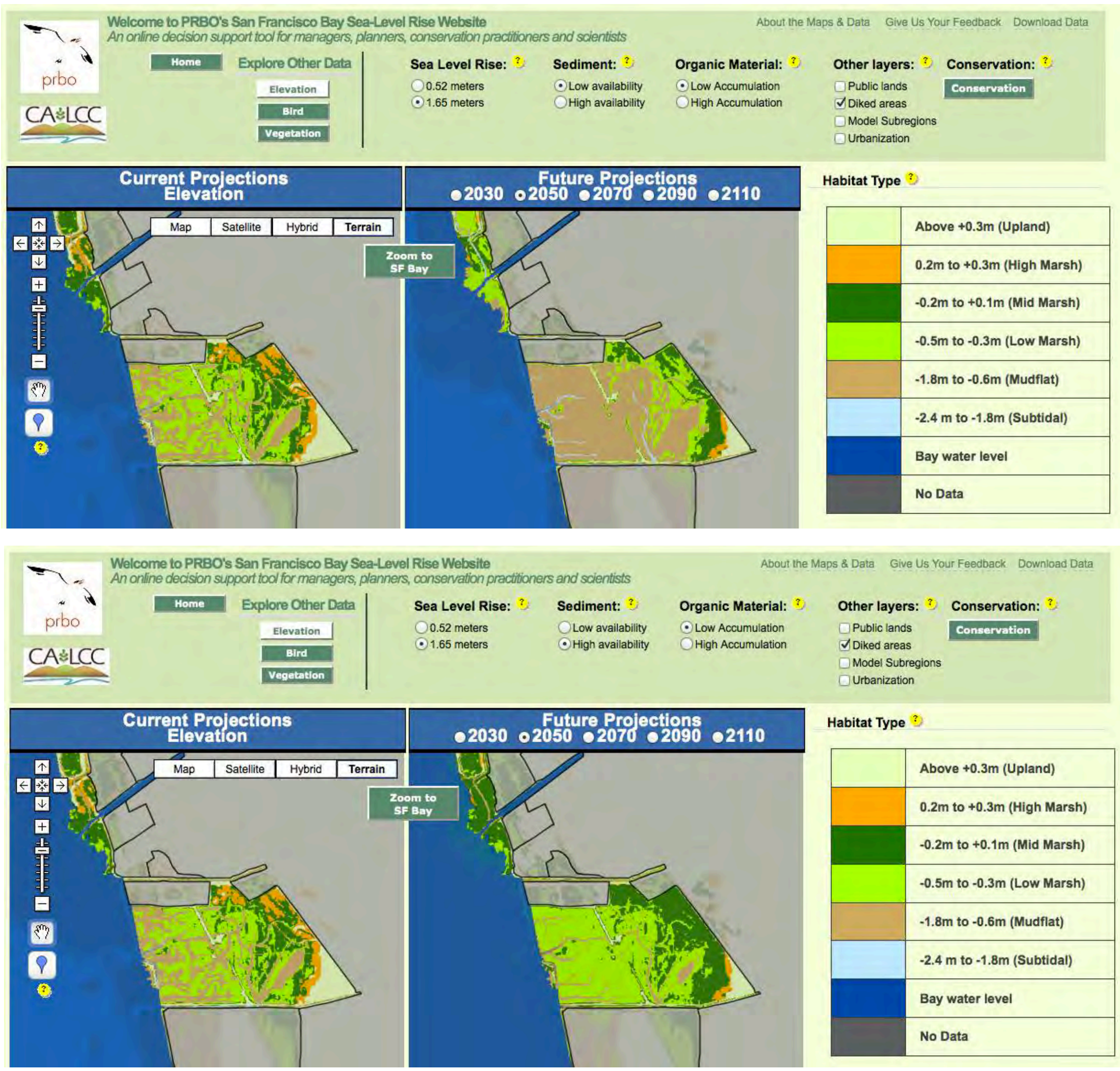
Currently, during storm events, especially those with wind waves, the bayside levee overtops, causing the Bay Trail to be unusable due to water damage and debris accumulation. More frequent overtopping during storm events could damage the bayside levee, not only affecting the Bay Trail but also the marsh it protects.

The marsh has limited adaptive capacity to accommodate or adjust to sea level rise or storm events. Upland migration opportunities are limited. While there are very few acres of upland in the southeast corner of the marsh, the marsh is surrounded by levees, and the adjacent inland areas are fairly urbanized. In addition, infrastructure either crosses (e.g., PG&E and EBDA utility lines) or bounds the marsh (e.g., the railroad right-of-way). These assets may be vulnerable to sea level rise, storm events and elevated groundwater, and will require further study to determine if they should be relocated or reinforced. Finally, while the bayside levee is actively maintained by EBRPD, it has proven difficult to obtain the necessary permits to raise or strengthen the levees protecting the Bay Trail and the marsh.[5]

Figure 9. Oro Loma Marsh is within the Hayward Regional Shoreline. The Bay Trail alignment follows the bayside levee. (Source: Google Maps)

[5] EBRPD obtains permits on an annual basis to repair the outer bay trail levee; however only small segments of repair are completed at a time due to permit conditions.

Figure 10. Predicted change in marsh habitat based on modeled average elevation relative to MHHW NAVD88 at Oro Loma Marsh by 2050 under a high rate of sea level rise, low rate of OM accumulation, and low (upper image) and high (lower image) sediment supply assumptions. Areas that are currently "diked" are shown in grey.



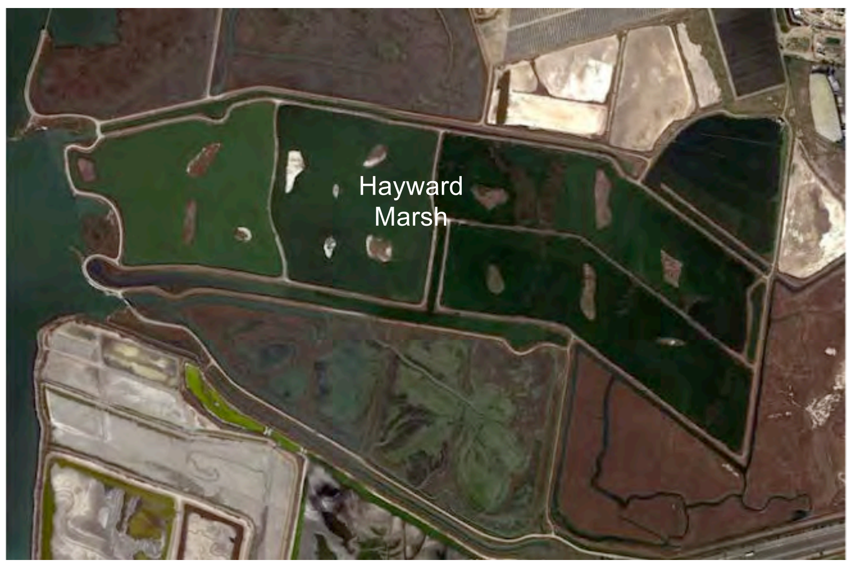
Managed Marsh Sensitivity and Adaptive Capacity

The ART project area contains five managed marshes. Four are within the Hayward Regional Shoreline, including Frank's Tract, West Winton, Hayward Marsh, and the Oliver Salt Ponds. The fifth is within the Eden Landing Ecological Reserve (ELER) at the southern end of the project area, which is a mixture of fully tidal and managed wetlands. The two ELER wetlands that have been restored to tidal action, Baumberg Tract and Whale's Tail, are considered in the previous tidal marsh section.

Hayward Marsh is somewhat unique compared to the other four systems (Figure 11). It is comprised of five managed ponds (3 freshwater and 2 brackish). The marsh receives secondary treated wastewater from Union Sanitary District and is subject to a National Pollution Discharge Elimination Permit (NPDES) from the Regional Water Quality Control Board. Flow through the ponds is controlled by a series of weirs, valves, and channels, which allow for the operation and management of the system[6]. Lastly, in the southeast corner of the marsh there is a 25-acre preserve that provides habitat for the federally endangered Salt Marsh Harvest Mouse.

Vertical Accretion
The PRBO tool evaluates through predictive modeling how resilient managed (diked) systems would be if in fact they were restored to full tidal action. There are a number of assumptions and caveats to this analysis; for example, initial habitat predictions are based solely on current elevations and not existing vegetation. The future predictions assume that in year 2010 these systems were returned to tidal action with the initial predicted habitat composition. It does not consider the time it would take for tidal marsh vegetation to colonize the area, nor any potential differences in mineral sediment or organic matter accumulation rates that would occur while vegetation was colonizing.

Figure 11. Hayward Marsh is a mixture of fresh and brackish ponds, with internal channels and islands. It relies on secondary treated wastewater from Union Sanitary District as a freshwater input. (Source: Google Earth)



Based on this analysis, the four managed systems within the Hayward Regional Shoreline would have varying capacities to persist over time depending on their initial elevation and the availability of mineral sediment (Table 6). Based on the assumed average initial elevations used in the PRBO tool, if returned to tidal action Frank's Tract would support mudflat, West Winton and Oliver Salt Ponds low marsh, and Hayward Marsh and ELER mid marsh.

With low sediment availability, by 2050, Frank's Tract would remain mudflat, West Winton and Oliver Salt Ponds would downshift to mudflat, and Hayward Marsh and ELER would downshift to low marsh. By 2090, all of the systems would transition to mudflat. With high

[6] http://www.ebparks.org/parks/hayward

sediment availability, by 2050 Frank's Tract would gain elevation to become, on average, a low marsh, while the other four systems would retain their initial marsh habitat. By 2090, all four systems would on average be at low marsh (Table 6 and Figure 12).

Figure 12. Frank's Tract and West Winton modeled predicted change in habitat to a uniform low marsh (based on elevation relative to MHHW) under high sediment availability in 2090.

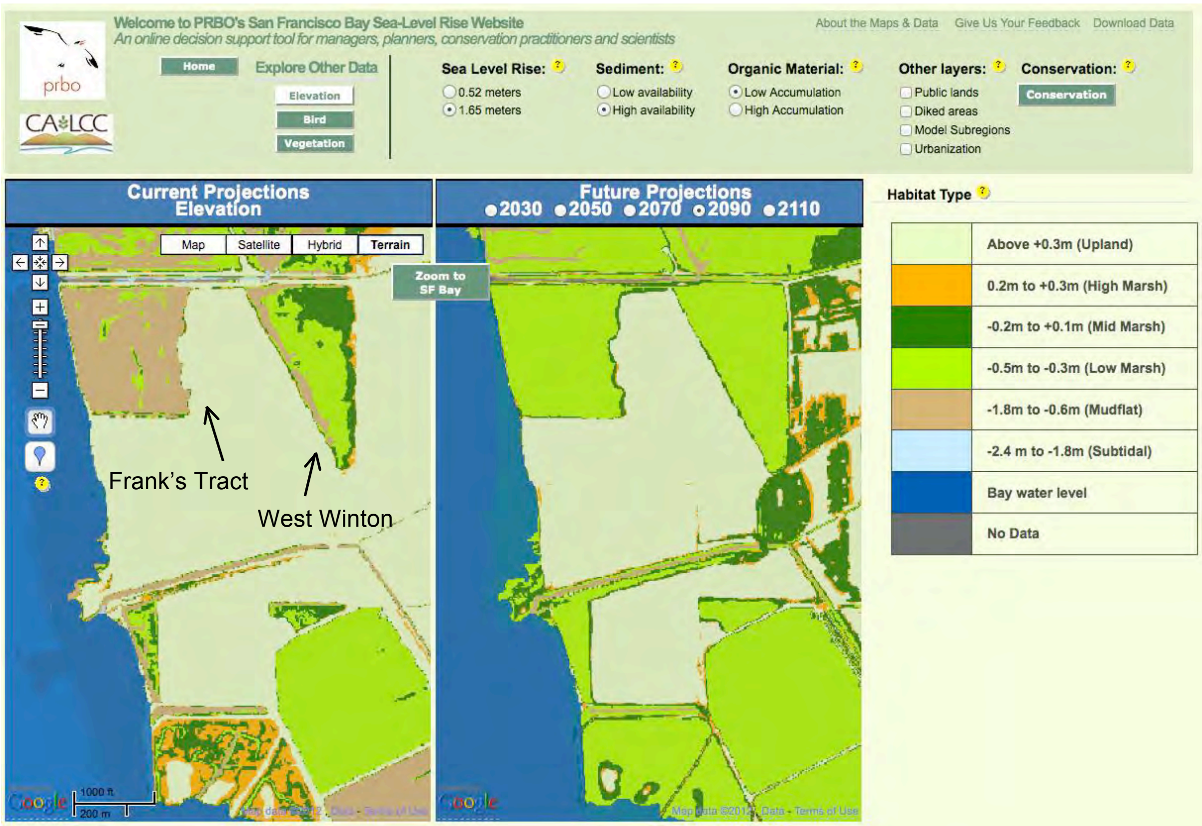


Table 6. Predicted change in average habitat type based on modeled average elevation relative to MHHW NAVD88 for assumed high and low sediment scenarios in combination with a high rate of sea level rise and low rate of OM accumulation.

Marsh Name	Assumed Initial (2010)	Low SSC 2050	Low SSC 2090	High SSC 2050	High SSC 2090
Frank's Tract	Mudflat	Mudflat	Mudflat	Low marsh	Low marsh
West Winton	Low marsh	Mudflat	Mudflat	Low marsh	Low marsh
Oliver Salt Ponds	Low marsh	Mudflat	Mudflat	Low marsh	Low marsh
Hayward Marsh	Mid marsh	Low marsh	Mudflat	Mid marsh	Low marsh
ELER	Mid marsh	Low marsh	Mudflat	Mid marsh	Low marsh

Upland Transgression

The potential for upland transgression, or the conversion of uplands to wetlands, for three of the five systems (Frank's Tract, West Winton, and Oliver Salt Ponds) if they were returned to tidal action is limited, mostly due to the minimal amount of upland habitat within these sites, and their location adjacent to existing urban development.

Under either the low or high sediment availability scenario, by 2050 the five systems are predicted to convert about half of the uplands available (Table 7). By 2090, all of these marshes will convert all available uplands to wetlands. As demonstrated by Hayward Marsh, the conversion of uplands does not always indicate a landward migration of wetland habitat. Upland areas within Hayward Marsh are islands that sit within the pond system. The conversion of these upland islands may not help to sustain the marsh system overall, but will provide habitat to tidal marsh species and will serve as tidal refugia for sensitive species for a period of time.

Table 7. Predicted acres of uplands converted to wetlands based on modeled average elevation relative to MHHW NAVD88 for assumed high and low sediment scenarios in combination with a high rate of sea level rise and low rate of OM accumulation. The data below constrains the uplands to adjacent natural, non-diked areas within the identified marsh footprint.

Marsh Name	Current Upland Acres (2010)	Percent Uplands Converted			
		Low SSC		High SSC	
		2050	2090	2050	2090
Frank's Tract	2.6	20	79	20	86
West Winton	1.0	47	48	47	68
Hayward Marsh	26.0	29	73	29	81
Oliver Salt Ponds	6.7	54	80	54	91
Eden Landing Ecological Reserve	485.9	47	71	47	87

Overall, if these managed systems were restored to full tidal action they would be sensitive to sea level rise and storm events given that they are at fairly low starting elevations. In addition, once restored to tidal action colonization of vegetation in these systems could be sensitive to changes in tidal regime or high-energy storm events.

If the dikes were *not* removed and all five wetlands were maintained as managed systems, they would be sensitive to potential overtopping and erosion of the shoreline structures that currently protect them from full tidal action. Additionally, tide control structures or gates used to maintain water surface elevations could be sensitive to higher Bay water levels, and may be difficult to operate or maintain if the frequency or intensity of storm events increases.

Specifically, for the Hayward Marsh, the levees are already in need of repair, and if there was damage to the levee system, the marsh may have to discontinue receiving treated wastewater to remain in compliance with the current NPDES permit. Furthermore, the freshwater and brackish ponds for this wetland provide final polishing to the secondary treated wastewater, and this function is sensitive to changes in salinity due to inundation or storm flooding. Lastly, the complexity of the operations, management, and permit compliance of the Hayward Marsh system means that there is less capacity to simply, easily, or in a low cost manner accommodate or adjust to changes from sea level rise or storm event impacts.

Consequences

Consequences are the magnitude of the economic, social, environmental and governance effects if an impact occurs. Factors that inform the magnitude of the potential consequences include the severity of the impact on the asset itself in terms of operations, maintenance, and capital improvement costs, the size and demographics of the population affected, the types of natural resources affected, and the jurisdictional complexity to manage the asset.

The consequences of sea level rise and storm events on wetlands will be significant to the natural resource functions, species and habitats within them, and to the inland areas protected by them. These larger consequences to inland areas from sea level rise and storm events are detailed in other chapters within this report.

Economy

There are potential direct and indirect economic consequences related to the exposure of wetlands to climate impacts. Many of the tidal marshes in the ART project area have been restored, representing a significant financial investment. There will be direct economic consequences if sea level rise increased the cost of restoration, including the cost to maintain or improve restoration projects. In addition, there could be direct costs in repairing utilities located within wetlands. For example, there are multiple utilities that transect the fully tidal Oro Loma Marsh, including power, wastewater and an abandoned gas pipeline. Furthermore, Hayward Marsh is a restored freshwater and brackish marsh system that serves as a discharge location for secondarily treated wastewater. The disruption or loss of this managed system will potentially have significant economic impacts on the utility that relies on it (Union Sanitary District).

Indirect consequences include the loss of ecosystem services that wetlands provide, including erosion and flood control through wave attenuation as well as water filtration and carbon sequestration. While it is difficult to quantify the dollar value of these services, Heberger (2009) points out that over $60 billion in infrastructure is at risk of inundation under high rates of sea level rise, and that some of this loss could be prevented by protecting and restoring tidal marshes.

Society

The complete or partial loss of tidal or managed marsh systems will potentially place shoreline residents at risk of flooding. Additionally, all of the fully tidal marshes in the ART project area have either been restored or are in process of being resorted. The ability to continue, maintain or expand the restoration industry and the employment that it provides will become more uncertain as sea level rises. Finally, tidal and managed marsh systems offer opportunities to view wildlife, provide access to the Bay shoreline, and offer scenic and aesthetic benefits that other areas cannot. The loss of these functions will have consequences for the people that use these areas for outdoor enjoyment or recreation.

Environment

In general, tidal marshes are predicted to either downshift from high to low marsh habitat or be lost as they convert to unvegetated intertidal mudflat under the high sea level rise scenario evaluated here. The consequence of this habitat shift would be significant for the a number of species of conservation concern, including state-listed or federally threatened and endangered species such as Clapper Rail, Black Rail and Salt Marsh Harvest Mouse, which rely on tidal marsh habitat either for breeding or foraging. For example, the loss of mid marsh, which is the primary breeding habitat for many bird species, could cause a significant reduction in bird abundance.

As marshes are subjected to more frequent or longer duration tidal inundation, there will be a loss of high tide refugia for species such as Clapper Rail and Salt Marsh Harvest Mouse, causing increased losses to predation, drowning or exposure. Additionally, in marshes that are adjacent to inland development, such as the Emeryville Crescent, repeated high tide inundation could force wildlife onto higher ground near Powell Street and I-80, causing increased stress on these populations. Lastly, more frequent inundation especially around the confluence with Temescal Creek could change soil salinities, affecting the survival marsh plant species and changing the vegetation profile over time.

Finally, many marshes are co-located with utility assets and impacts to these utilities as a result of sea level rise and storm events could have secondary impacts on water and habitat quality.

Governance

While wetlands are often managed by single agencies, wetland restoration programs require the collaboration of many different entities, from local to federal agencies and non-governmental organizations to private landowners. There may be a wide variety of agencies and organizations involved with wetland restoration and protection, which presents challenges in the many phases of decision-making:

- Planning and funding (e.g., San Francisco Bay Joint Venture)
- Regulation (e.g., U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, San Francisco Bay Conservation and Development Commission, and San Francisco Bay Regional Water Water Quality Control Board
- Restoration design (e.g., Phillip Williams & Associates – Environmental Science Associates)
- Land management (e.g., National Parks Service, California Department of Fish and Game, and East Bay Regional Parks)
- Research (e.g., United States Geological Survey and PRBO Conservation Science)

The fact that there is no single, individual institutional decision-maker for wetland restoration and protection presents challenges for effective and timely management of these assets.

Key Findings

The vulnerability of twelve tidal marshes and five managed marshes in the ART project area was assessed in collaboration with PRBO Conservation Science using data from their sea level rise online decision support tool. The sensitivity and adaptive capacity of these marshes was assessed based on select information in this tool, including current habitat composition; changes in future projected habitat based on elevation modeling; the conversion of uplands to wetlands based on elevation modeling, and changes in landscape conservation priority ranking. These indicators of vulnerability were evaluated for PRBO's predictive modeling of a high rate of sea level rise, which corresponds to approximately 16 inches of sea level rise at 2050 and 55 inches at 2100, and two future assumed suspended sediment concentration rates (low and high) for two time periods (2050 and 2090).

The PRBO modeling results suggest that marshes are sensitive to a high rate of sea level rise, and that their capacity to persist over time will depend on sediment supply. Overall, within the ART project area marshes will downshift from higher to lower elevation habitat types, and eventually to mudflat. Under the more pessimistic sediment supply assumption (low availability), marshes are more sensitive to sea level rise. For example, under the low sediment scenario most of the marshes in the ART project area will not persist. Instead, they will transition to mudflat by 2050. Under the high sediment supply scenario all but one of the marshes will persist in 2050, with some downshifting in habitat type. By 2090 only one additional marsh will be lost to mudflat, while the remainder will downshift to low marsh habitat under the high sediment supply scenario.

Almost half of the uplands within the marsh system footprint will be converted to wetland habitat (low, mid or high marsh) by 2050 regardless of sediment supply. Under the high sediment supply scenario, approximately 75% of the uplands will convert to wetlands by 2050, with additional conversion by 2090. For many of the marshes in the ART project area there is minimal opportunity for upland transgression due to existing constraints such as adjacent land uses, including developed or diked areas, and the elevation of the available uplands.

Five managed marshes were assessed. If the existing dikes were removed, and these systems were restored to full tidal action, they would be sensitive to a high rate of sea level rise as they are at fairly low starting elevations. In addition, the colonization of vegetation in these areas to create marsh habitat once restored to tidal action could be sensitive to changes in tidal regime or high-energy storm events. If the dikes were *not* removed these systems would be sensitive to potential overtopping and erosion of the shoreline structures (non-engineered earth berms, etc) that currently protect them from full tidal action. Additionally, tide control structures or gates used to maintain water surface elevations could be sensitive to higher Bay water levels, and may be difficult to operate or maintain if the frequency or intensity of storm events increases.

The Hayward Marsh, which is unique compared to the other managed marshes in the ART project area, is sensitive to sea level rise, has limited adaptive capacity, and there will be high consequences if this system is exposed to sea level rise or storm events. The freshwater and brackish ponds in the marsh provide final polishing to the secondary treated wastewater, and this function is sensitive to changes in salinity. The marsh is protected by a series of levees that are already in need of repair and are therefore already sensitive to storm events. The complexity of the operations, management and permit compliance of both the operation of this marsh system and the maintenance and upgrade of the levees that protect it means there is limited capacity to simply, easily or in a low cost manner accommodate or adjust to changes from sea level rise or storm event impacts.

As marshes are exposed to more frequent or longer duration tidal inundation, there will be a loss of high tide refugia for species such as Clapper Rail and Salt Marsh Harvest Mouse, causing increased losses to predation or drowning. Additionally, for marshes that are adjacent to urbanized areas repeated high tide inundation could force wildlife to higher ground that is closer to people and infrastructure, causing increased stress on these populations.

References

Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project. November 2011. Consulting report prepared by AECOM and Arcadis for the San Francisco Bay Conservation and Development Commission, Metropolitan Transportation Commission and the California Department of Transportation. Available at http://www.mtc.ca.gov/news/current_topics/10-11/sea_level_rise.htm.

Heberger M., Cooley H., Herrera P., Gleick P.H., and E. Moore, 2009, The Impacts of Sea-level Rise on the California Coast. A paper from the California Climate Change Center (CEC-500-2009-024-F). Pacific Institute. Available at: http://www.pacinst.org/reports/sea_level_rise/report.pdf.

The Nature Conservancy and NOAA National Ocean Service Coastal Services Center, 2011, Marshes on the move: A manager's guide to understanding and using model results depicting potential impacts of sea level rise on coastal wetlands. Available at: www.csc.noaa.gov/publications/Marshes_on_the_move.pdf

Schoellhamer DH (2011) Sudden clearing of estuarine waters upon crossing the threshold from transport- to supply- regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999. Estuaries & Coasts 34: 885–899.

Stralberg D., Brennan M., Callaway J.C., Wood J.K., Schile L.M., *et al*., 2011, Evaluating Tidal Marsh Sustainability in the Face of Sea-Level Rise: A Hybrid Modeling Approach Applied to San Francisco Bay. PLoS ONE 6(11): e27388. doi:10.1371/journal.pone.0027388.

Veloz, S., N. Nur, L. Salas, D. Stralberg, D. Jongsomjit, J. Wood, L. Liu, and G. Ballard, 2012, San Francisco Bay Sea-Level Rise Website. A PRBO online decision support tool for managers, planners, conservation practitioners and scientists. Phase II report to the California State Coastal Conservancy. Available at: http://data.prbo.org/apps/sfbslr/PRBOCoastalConservancyTechnicalReport_Mar2012.pdf (Accessed June 19, 2012).

Chapter 8. Parks and Recreation Areas

Parks and recreation areas in the ART project area provide a wide variety of services to the public. Resources and activities at these sites include scenic views; walking, running, and biking on paths and trails; nature viewing; interpretive displays; educational facilities and activities; swimming; paddleboating; sailboarding; motorboating; picnicking; playgrounds; family/group event areas and facilities; dog recreation; historic or cultural activities; team sports; and golf. Parks and recreational areas in the ART project area serve users at three scales:

- Regional shoreline areas that attract visitors from the entire Bay Area and beyond;
- Parks or community centers that provide event and sports facilities used primarily by Alameda County residents; and,
- Small shoreline parks that serve a surrounding community or neighborhood.

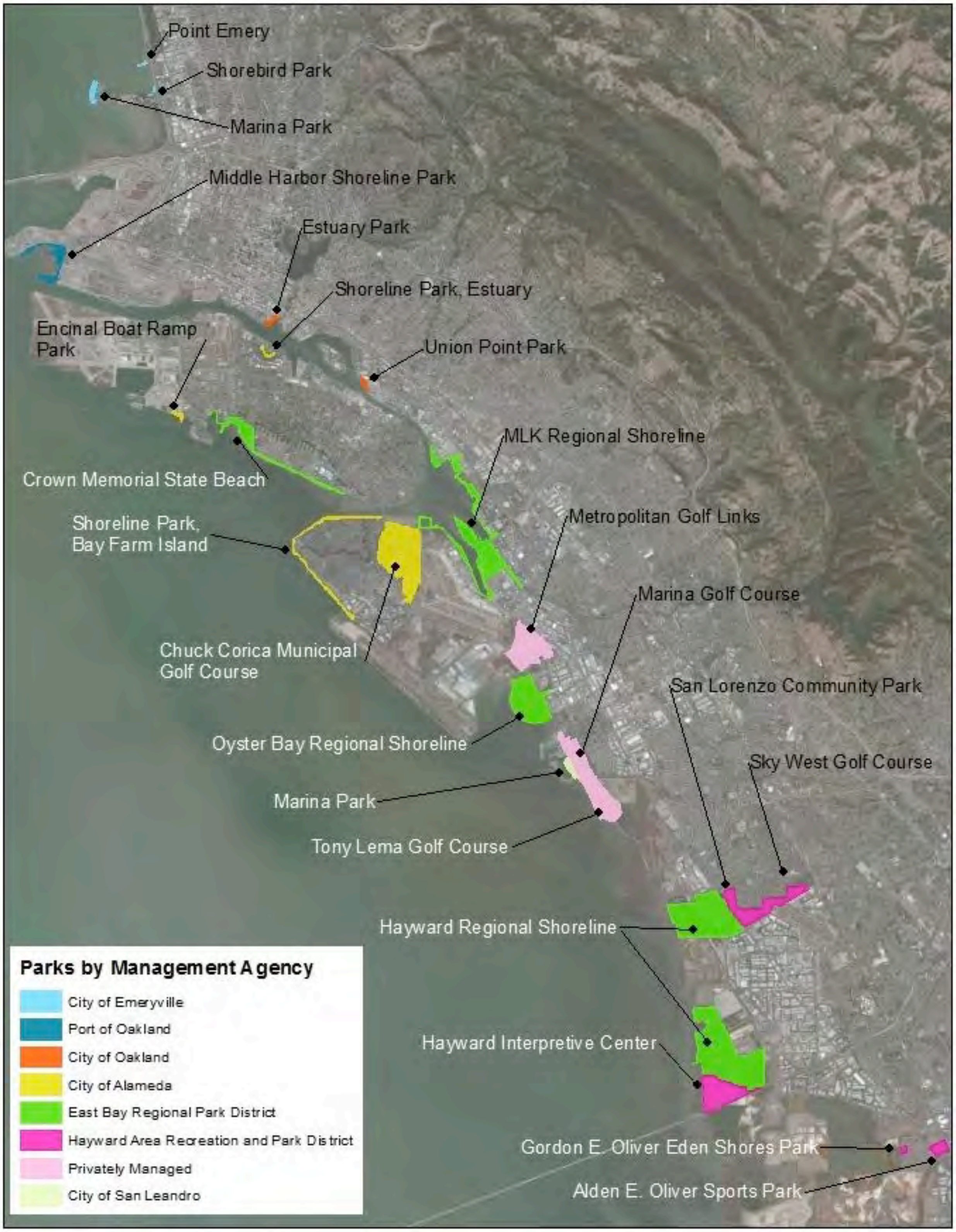
This section focuses on the vulnerability and risk to 18 parks, 5 golf courses (Figure 1) and the San Francisco Bay Trail in the project area from sea level rise impacts. These sites are representative of the different recreation services and scales of use in the subregion, but are not all-inclusive of parks and recreation areas within the project area. In particular, only a few of the subregion's numerous neighborhood parks are addressed here.

Exposure

Exposure is the extent to which an asset, in this case a park or golf course, experiences a specific climate impact such as storm event flooding, tidal inundation, or elevated groundwater. The exposure of parks and recreation assets in the ART project area to two sea level rise projections and three Bay water levels was evaluated. The two sea level rise projections, 16 inches (40 cm), and 55 inches (140 cm), correlate approximately to mid- and end-of-century. These two sea level rise scenarios were coupled with three Bay water levels: the new daily high tide, measured as mean higher high water (MHHW), the new 100-year extreme water level, also known as the 100-year stillwater elevation, and the 100-year extreme water level coupled with wind waves, hereafter "storm event with wind waves," or "wind waves." These water levels were selected because they represent a reasonable range of potential Bay conditions that will affect flooding and inundation along the shoreline. For each exposed facility, the average depth of inundation from the daily high tide and storm events was calculated. Whether a facility is exposed to wind waves was evaluated as a simple binary – yes or no. For more information about sea level rise projections and Bay water levels evaluated see Chapters 1 and 2.

For each park and golf course, the extent exposed to each sea level rise projection and Bay water level was determined (see Appendix C). For many of the parks, the total park acreage includes submerged areas. To avoid a gross misrepresentation of the exposure percentages, the analysis was based on the land area of the park. This land area, or footprint, was visually determined and digitized in GIS using aerial imagery in combination with maps that show park boundaries. Therefore the footprint values in Table 1 are approximations, as are the calculated exposure percentages.

Figure 1. Park and recreation areas in the ART project area.



Parks with more than 25% of their footprint directly affected by a sea level rise scenario are considered significantly exposed. The selection of this threshold was based on exposure of specific amenities such as trails, buildings, restrooms, picnic tables and other amenities within each park. For most parks, inundation or flooding exposure greater than 25% coincides with exposure of most park amenities. Exceptions to this are noted in the discussion below.

It is important to note that the approach used for the exposure mapping is not appropriate for a dynamic system like a beach. For beaches at Crown Memorial State Beach and Point Emery the analysis relies on the best professional judgment of the park managers about the likely exposure to future sea level rise (based on past events and current situation).

Daily high tide inundation

With 16 inches of sea level rise, Hayward Regional Shoreline and the Chuck Corica Golf Course (on Bay Farm Island in Alameda) would be exposed to inundation by the new daily high tide (Column A in Table 1). A large portion of Martin Luther King Jr. Regional Shoreline would also be subject to tidal inundation with 16 inches of sea level rise, but the area exposed is primarily salt marsh habitat and does not include built recreation amenities. Eight parks and two golf courses are significantly exposed to new daily high tides with 55 inches of sea level rise (Column D in Table 1). As sea level rises, exposure to the new high tide could result in a slow yet chronic degradation of assets that cannot accommodate or adjust to new conditions.

Storm event flooding and exposure to wind waves

Seven parks and two golf courses would be exposed to storm event flooding with 16 inches of sea level rise. At Crown Memorial State Beach, with less than 20% of the park footprint exposed to storm flooding, critical amenities including the majority of picnic areas and two restrooms would likely be affected (Column B in Table 1). With 55 inches of sea level rise, all but two parks and three golf courses are significantly exposed to storm event flooding. (Column E in Table 1)

In tandem with the extreme water, during storm events there is a greater likelihood of wind waves that can lead to overtopping and erosion of the shoreline and shore protection. During storm events that generate wind waves, areas exposed to the 100-year storm flooding (i.e., Columns B and E in Table 1) would also be exposed to greater flooding depths due to wind waves in these areas. This is because wind-driven waves can elevate Bay water levels significantly, causing overtopping of shore protection by one-half to more than three feet. However, as the wind waves travel inland they tend to dissipate and the additional wind wave-caused flood depths will decrease.

Assets exposed only to wind waves, and not to storm event flooding, could potentially be exposed to shallow flood depths for short durations. With 16 inches of sea level rise, the additional land area exposed to only wind waves is significant for eight parks in the ART project area (Column C in Table 1). With 55 inches of sea level rise, no additional assets are significantly exposed to wind waves only; that is, areas exposed to wind waves are already exposed to 100-year storm flooding.

Table 1. Exposure of parks and recreation areas in the ART project area to sea level rise impacts. All facilities exposed to storm event flooding are also within the wind wave zone; the percent in columns C. and F. are exposed *only* to wind waves.

		16" SLR			55" SLR		
		Daily High Tide	Storm event		Daily High Tide	Storm event	
Parks and Recreation Areas (Listed from North to South in the project area)	Total Land Acres*	% exposed	% exposed	% exposed to wind waves only	% exposed	% exposed	% exposed to wind waves only
1. Point Emery	1.4	6	20	46	36	67	31
2. Shorebird Park	1.1	3	11	14	16	25	47
3. Marina Park, Emeryville	13.2	1	12	34	22	48	38
4. Middle Harbor Shoreline Park (Port View Park)	44.8	1	4	32	6	34	35
5. Estuary Park & Aquatic Ctr	7.2	2	81	17	93	98	0
6. Shoreline Park, Estuary	3.8	2	9	74	19	81	15
7. Union Point Park	6.7	0	1	64	2	60	30
8. Encinal Boat Ramp Park	7.1	3	10	88	12	98	1
9. Crown Memorial Beach	80.1	0	19	50	29	67	21
10. Chuck Corica Municipal Golf Course	314.1	95	98	2	99	100	0
11. Shoreline Park, Bay-Farm Island	38.4	4	19	62	25	76	23
12. Martin Luther King, Jr. Reg. Shoreline	217	42	62	31	77	93	7
13. Metropolitan Golf Links	172.7	0	1	26	13	28	22
14. Oyster Bay Reg. Shoreline	186.8	1	1	2	2	3	6
15. Marina Park, San Leandro	18.8	2	5	68	15	77	13
16. Marina Golf Course	94.5	0	55	32	62	89	10
17. Tony Lema Golf Course	128.8	1	12	15	14	29	19
18. Hayward Reg. Shoreline	791.4	69	96	4	99	100	0
19. San Lorenzo Park	24.3	0	92	7	96	100	0
20. Skywest Golf Course	123.1	0	12	13	15	25	9
21. Hayward Shoreline Interpretive Center	144.7	7	99	1	100	100	0
22. Gordon E. Oliver Eden Shores Park of Hayward	5.6	0	49	51	80	100	0
23. Alden E. Oliver Sports Park of Hayward	26.5	0	0	100	90	100	0
24. San Francisco Bay Trail — Total	105**	3	21	35	32	56	16
24. San Francisco Bay Trail — *Class I*	*80***	*2*	*24*	*31*	*33*	*54*	*14*
24. San Francisco Bay Trail — *Class II*	*24***	*4*	*24*	*50*	*29*	*64*	*19*

* Acreage does not include portions of the parks that are submerged, therefore acreages listed in this table do not match the total site acreages for many of the parks and golf courses.

** Class I trails are physically separated from streets and roadways. Class II trails are on-street.

Sensitivity and Adaptive Capacity

The sensitivity and adaptive capacity of park and recreation assets in the ART project area was assessed for three potential climate impacts that could occur due to sea level rise and storm events. The three climate impacts considered are:

- More frequent or longer duration flooding during storm events
- Permanent or frequent inundation by the daily high tide
- Elevated groundwater levels and saltwater intrusion

Sensitivity is the degree to which an asset or entire system would be physically or functionally impaired if exposed to a climate impact, and adaptive capacity is the ability for an asset or system to accommodate or adjust to a climate impact and maintain or quickly resume its primary function. The sensitivity and adaptive capacity was evaluated for both specific facilities (e.g., a boat launch, an interpretive center, etc.) and universal features such as parking lots, access pathways, and bathrooms.

<u>Recreational Activities</u>

Walking, Running, Hiking and Biking

The designated portions of the Bay Trail along the shoreline provide most of the walking, running, hiking and biking opportunities in the project area. The Bay Trail is also an important commute corridor that provides safe access to jobs and schools for bicyclists. Within most parks, short access paths connect different recreation amenities (e.g., parking lots, restrooms, lawn areas, launch docks, etc). Oyster Bay Regional Shoreline also has long paths that are not part of the Bay Trail.

The sensitivity of trails and paths to tidal inundation, storm flooding, and elevated groundwater varies depending on the trail elevations and locations (e.g., alignment on a levee, in a low-lying area, or along a road), construction materials (e.g., paved, gravel, dirt, etc), connectivity to other trails and transportation routes, and existing conditions. Laura Thompson, Bay Trail Project Manager, notes that the Bay Trail is currently affected by flooding and extreme weather events. For example, a trail segment along a levee in San Leandro was damaged by storm flooding a few years ago and was closed for a period of time for repairs. More frequent storm flooding and/or daily high tide inundation would cause more trail closures and leave lasting damage to trail surfaces and levees. Specifically, pooling can occur on the trails when water overtops the trail or groundwater seeps up through the trail surface. Some trail users might still be able to use a portion of trail that has been compromised by flooding, but this depends on the specific circumstances of the flooding and the user. Factors such as mud and debris, or ponding around a trail in an area where drainage is poor could prevent even the most intrepid pedestrian or biker from passing through. Furthermore, minor pooling or damage to trail surfaces can make segments impassable for persons with limited mobility and trail users in wheelchairs.

The adaptive capacity of trails varies within the project area. Along developed areas of the shoreline in the northern portion of the project area, alternative routes on streets may be available to allow trail users to bypass closed Bay Trail segments. These alternative routes will usually be less safe and less likely to provide a quality recreational experience than the designated Bay Trail, which consists primarily of Class I (off-street, multi-use) trails within the project area. Furthermore, alternative on-street routes might also be unusable due to flooding impacts. Bay Trail segments and other trails through the southern portion of the study area between San Leandro and Highway 92 have relatively few access points and are far removed from parallel transportation routes. Damage to the trails along this stretch of shoreline would likely necessitate closing large segments of the trail system. Closures such as these will reduce access to nature and wildlife viewing and interpretive signage along the Hayward shoreline. Similarly, impacts to the Bay Trail segments within Martin Luther King Jr. Regional Shoreline would limit these opportunities around San Leandro Bay and Arrowhead Marsh.

The trail segments within regional parks managed by the East Bay Regional Park District and Hayward Area Recreation and Park District could benefit from these agencies' organized park management and their ability to enlist volunteer support for trail cleanup and restoration, which contribute to adaptive capacity. In general, however, the close proximity of recreational trails to the shoreline, and their combined high sensitivity and low capacity to accommodate or adjust to flooding and other impacts make walking, hiking, running and biking activities in the project area very vulnerable to sea level rise.

Passive Recreation and Family and Group Gatherings

Facilities for passive recreation and family and group activities include picnic tables, barbeques, playgrounds, lawn areas, and event space or facilities for rent. Of the 18 parks assessed in the ART project, twelve have picnic tables and barbeque grills, lawn areas and/or playgrounds (Table 2). Within each of these parks, exposure of these amenities to sea level rise and storm events is closely correlated to the overall exposure of the park's total land acreage shown in Table 1. Among this subset, Estuary Park, Martin Luther King Jr. Regional Shoreline, Gordon E. Oliver Eden Shores Park, and San Lorenzo Park are likely to experience significant flooding of these amenities during a storm event with 16 inches of sea level rise. While this represents relatively few of the parks in the project area, all four are heavily used for passive recreation and family and group events, and the loss of these services could increase demands on other nearby parks that might not be able to accommodate more use. It is likely that parks that already experience flooding issues due to poor drainage, such as San Lorenzo Park, will experience more frequent flooding with much less than 16 inches of sea level rise.

Table 2. Passive Recreation Facilities (Parks with higher vulnerability are indicated in orange)

Park	Picnic	Lawn	Playground
Marina Park (Emeryville)	*		
Middle Harbor Shoreline Park	*	*	
Estuary Park		*	
Union Point Park	*	*	*
Crown Memorial State Beach	*	*	
Shoreline Park (Bay Farm Is.)	*	*	
Martin Luther King Jr. Reg. Sh.	*		
Oyster Bay Regional Shoreline	*		
Marina Park (San Leandro)	*	*	*
San Lorenzo Park	*	*	*
Gordon E Oliver Eden Shores Park	*	*	*
Alden E. Oliver Sports Park	*		*

Picnic tables and playgrounds are not likely to be sensitive to occasional flooding and could be used by most visitors as soon as the water recedes. However, persons with limited mobility and wheelchair users are sensitive to minor impacts (e.g., muddy conditions, ponding on trails and in gathering areas), and therefore these facilities may be inaccessible to them for longer periods after flooding events. Lawns and other planted areas are likely to suffer damage from exposure to salt water and will require time to recover or re-vegetate. With repeated Bay flooding, lawn areas and other non-salt tolerant plantings would probably not survive. Managers do not have many options for relocating lawn areas because space at most parks is limited. Despite some of these challenges, passive recreation activities in the project area would be only moderately vulnerable to sea level rise impacts because the amenities that support these activities are present throughout the park system and, in many cases, resilient to impacts and/or usable when partially impaired.

Space or facilities that can be reserved or rented for gatherings (e.g., classes, weddings, meetings, and parties) are more vulnerable to climate impacts. These facilities are in high demand and, for some parks, provide important revenues. Indoor event spaces located at Estuary Park (Aquatic Center), Martin Luther King Jr. Regional Shoreline, San Lorenzo Park and the Hayward Shoreline Interpretive Center are available for groups to reserve and/or rent. All are likely to be exposed to storm flooding with 16 and 55 inches of sea level rise. This type of flooding would be unlikely to affect the structural integrity of the facilities, but it could cause damage (e.g., water damage to floors) that would make these facilities less desirable or unusable for events. Site managers may be able to take temporary measures to prevent and/or recover from damage (e.g., laying out sandbags or pumping out flood water), which would enable them to avoid or minimize the effects of occasional flooding.

Sports Facilities

Team or field sports facilities include artificial turf and grass playing fields, as well as basketball and tennis courts. In the northern portion of the ART project area a few of the parks have or are adjacent to grass sports fields. Estuary Park has a grass soccer field, and Encinal Boat Ramp Park, Crown Memorial State Beach and Martin Luther King Jr Regional Shoreline are connected recreation areas with grass playing fields and tennis courts. Major sports facilities are clustered at the southern end of the project area at San Lorenzo Park, Gordon E. Oliver Eden Shores Park and Alden E. Oliver Sports Park under the management of the Hayward Area Recreation and Park District (HARD). Managers at HARD have identified poor drainage as an existing cause of flooding during periods of heavy rains. All three parks drain into adjacent marshes or waterways that will have elevated flood levels during storm events with 16 inches of sea level rise. Already, baseball fields at San Lorenzo Park flood when it rains. If grass sports fields are exposed to more frequent flooding, managers will be forced to temporarily close the fields and sports courts while the water drains. At San Lorenzo and Alden Sports Parks, closures would reduce revenues that help support the costs of park maintenance.

With 16 inches of sea level rise, wind waves are likely to overtop flood protection and levees during big storm events, leading to saltwater exposures in these parks as well as the fields along the Alameda and Oakland shorelines, which would cause lasting damage to grass soccer and baseball fields. Under this scenario, the project area could be left with few undamaged soccer or baseball fields. Artificial turf fields and basketball and tennis courts are more resistant to salt water damage, but they might be unusable immediately after storm events due to temporary flooding. All of these impacts would lead to more closures and maintenance and repair costs.

Exposure to sea level rise impacts varies dramatically at the five golf courses located in the ART project area. By mid-century, Chuck Corica Golf Course on Bay Farm Island in Alameda could be completely inundated by daily high tide, and over half of the Marina Golf Course (part of the Monarch Bay Golf Complex) in San Leandro could be affected by storm event flooding. In contrast, Metropolitan Golf Links, Tony Lema Golf Course and the Skywest Golf Course are minimally exposed (in acreage percentage) to climate impacts with 16 inches of sea level rise. At 55 inches of sea level rise, storm events are likely to cause significant flooding and exposure to wind waves in these three golf courses. However, substantial portions of each golf course (i.e., greater than 70% of the course footprint) may be unaffected even with end of century sea level rise, offering opportunities to reconfigure the courses to maintain these golfing resources.

Golf courses could be especially sensitive to sea level rise impacts, even at low levels of exposure. Grass that is exposed to saltwater even briefly (e.g., due to storm driven wind waves) may be damaged, requiring significant time and maintenance resources to return the course to a suitable playing standard. Even if managers can avoid shutting the entire course by closing only the portion(s) under repair, the course may be much less desirable and lose clients. Golfing opportunities for persons with limited mobility will be especially vulnerable because these visitors will have more difficulty using impaired facilities. Furthermore, Marina Golf Course, the only fully accessible par course in the project area, would be significantly affected by storm flooding with 16 inches of sea level rise.

Existing stressors on some of the golf courses are likely to make them more sensitive to sea level rise and storm event impacts within a shorter timeframe. For example, managers currently must close portions of the Skywest course during rainy weather because of flooding caused by poor drainage. Any increase in Bay water levels would exacerbate this issue, leading to more frequent closures, higher maintenance and repair costs, and lost revenues. Most golf courses are expected to be revenue generators, but both Chuck Corica and Skywest golf courses have had operating losses in recent years. The exposure analysis does not address salinity intrusion into groundwater supplies, but these are also likely to affect golf courses (such as the Skywest course) that are irrigated with groundwater pumped on site. Higher groundwater levels could compromise underground irrigation systems, especially valves and controllers.

Overall, existing problems such as poor drainage, as well as high sensitivity of grass turf and other non-salt tolerant plants to salt water exposure suggest that opportunities in the ART project area for certain team sports (i.e., soccer and baseball) and golfing will be highly vulnerable to sea level rise and storm events. Moreover the shrubs and trees that help create the character of these shoreline places may be compromised, affecting the aesthetic qualities that attract the public to the shoreline.

Nature and Wildlife Viewing

The most notable sites for nature and wildlife viewing in the project area are tidal marshes at Elsie Roemer Bird Sanctuary and Crab Cove (at Crown Memorial State Beach), Arrowhead Marsh (at Martin Luther King Jr. Regional Shoreline), Hayward Regional Shoreline and Hayward Shoreline Interpretive Center. At their current elevations, these sites would be exposed to a sea level rise of 16 inches. Sediment accretion in some of the marshes might increase the marsh elevation at a rate commensurate with sea level rise. This outcome depends on current marsh elevation and future availability of sediment. If accretion cannot keep up with the rate of sea level rise, high- and mid-marsh habitats will likely be replaced by low-marsh, mudflats, and sub-tidal areas by the end of the century (Stralberg et al. 2011). This would result in population declines of marsh birds such as Song Sparrows and Marsh Wrens that are of interest to birdwatchers (Veloz et al. 2012). In the meantime, these marshes are likely to remain valuable habitat for shorebirds, and, as such, popular destinations for wildlife enthusiasts.

At Elsie Roemer, Crab Cove and Arrowhead Marsh, which have areas directly subject to tidal action, the types of species that can be seen and the amount of time that they are present will change as the sites experience longer periods of inundation each day. Even in marshes that successfully keep up with sea level rise, the quality of wildlife viewing opportunities may decline as repeated flooding reduces the resilience of these habitats to changes, such as invasive species and erosion.

Although sea level rise and storm events will have direct impacts on inter-tidal habitats, nature and wildlife viewing will be more acutely impaired by sea level rise impacts to the Bay Trail and, in some locations, parking areas. In particular, damage to levee trails that offer some of the best nature and wildlife viewing in the project area will reduce these opportunities for persons with limited mobility. Additionally, higher tides that drown mudflats and marshes or squeeze buffer areas between trails and habitats could cause wildlife to abandon some areas altogether, which would be another indirect effect of sea level rise on wildlife viewing opportunities.

Interpretive and Educational Activities

Parks in the ART project area showcase the natural, historic and cultural resources of the East Bay shoreline. Crab Cove Visitor Center at Crown Memorial State Beach and the Hayward Shoreline Interpretive Center attract thousands of visitors every year for interpretive and educational programs. Neither of these centers is likely to experience significant damage due to storm flooding or daily high tide inundation with 16 inches of sea level rise. However, implementing measures to prevent flood damage (e.g., sandbags) and recover from minor flooding impacts (e.g., water damage to floors) would increase management and maintenance costs and cause unplanned closures. The value of these two centers as interpretive and educational resources is closely linked to their surrounding natural features. Sea level rise impacts that change characteristics of the tidal zone at Crab Cove and the marshes in Hayward, and which limit access to these areas, will directly affect programs that are hosted at these facilities. For example, longer-lasting daily inundation at Crab Cove will limit the availability of a wheelchair-accessible ramp that is used by school groups and members of the public to explore tidepools at low tide. Managers of these facilities have opportunities to adapt interpretive and educational programs to reflect the changing natural resources.

Many of the parks in the project area, such as Hayward Regional Shoreline, have interpretive signage along trails. In contrast with the two interpretive centers discussed above, the sensitivity and adaptive capacity of existing signage is less relevant for understanding how interpretive and educational services are vulnerable to sea level rise and storm events because this signage will need replacing well before mid-century. Again, managers have sufficient opportunity to adapt signage content and placement to changing conditions. Interpretive and educational services in the project area may even benefit from changes associated with sea level rise that offer new ways to capture the interests of and engage with park visitors.

Water Sports Access and Facilities

Public access onto the water for swimming, sailboarding (e.g., windsurfing and kitesurfing), paddleboating (e.g., kayaking, paddleboarding, sculling, outrigger canoeing) or motor boating is available at seven of the parks in the project area (Table 3).

Table 3. Water Sports Facilities (Parks with higher vulnerability are indicated in orange)

Park	Swimming	Paddle-boating	Sail-boarding	Motor boating
Point Emery	*	*	*	
Marina Park (Emeryville)		*	*	*
Middle Harbor Shoreline Park		*		
Estuary Park		*		
Encinal Boat Ramp Park		*		*
Crown Memorial State Beach	*	*	*	
Martin Luther King Jr. Reg. Sh.		*		*

Beaches at Point Emery and Crown Memorial State Beach offer opportunities for swimming and wading in the Bay. As noted previously, the exposure mapping approach used in this assessment is not appropriate for dynamic systems such as beaches. Based on the best professional judgment of managers familiar with these parks, both of these sites are likely to be exposed to mid-century high tide inundation and storm event flooding that would erode these beaches. Point Emery is already eroding rapidly and would require significant and expensive shoreline protection improvements to maintain the park's current size. Even with these measures, the beach cannot be maintained with sea level rise.

According to park managers, Crown Memorial State Beach is also eroding, and requires re-nourishment periodically to maintain this very popular beach. (The next re-nourishment is planned for 2013-2014.) This management practice affords the park some capacity to address sea level rise impacts to the beach because the responsible agencies (i.e., the park manager, East Bay Regional Park District and the two owners, the City of Alameda and California State Parks) have experience with beach nourishment as a management practice at the site. However, the park may be at a disadvantage for receiving immediate attention after a storm event that causes widespread damage because the District does not own the site and might have to give priority to other parks that it owns and manages. At some point it is likely that storm erosion will occur so frequently that costs for re-nourishment become prohibitive. Loss of this unique beach access and the recreational opportunities at Crown Memorial park would be a significant to the Alameda community and the entire Bay Area.

Sailboarding and swimming opportunities in the project area are similarly sensitive to mid-century sea level rise impacts. Point Emery, Marina Park in Emeryville and Crown Memorial State Beach are popular sites for sailboarding due to their uniquely favorable wind conditions and access onto the Bay. As discussed above, the beaches at Point Emery and Crown Memorial from which the sailboarders launch are quite vulnerable to erosion with sea level rise. Impacts that reduce the number of days when visitors can sailboard and paddleboard at Crown Memorial State Beach would also hurt revenues of the rental concession at this site.

The stairs used to launch sailboards at Marina Park are less exposed and sensitive to mid-century flooding than the beaches. However, this location is much less desirable for launching and sailing and, unlike the beaches, can only accommodate one user at a time. Other parks north of the project area offer launch sites for sailboarding that, if resilient to sea level rise impacts, could accommodate some displaced users, but they too might be impaired by storm events. In general, efforts to recover (i.e., to re-open a site) after a flooding event, and plan for ways to extend the "usable life" of these sites for sailboarding will benefit from having an engaged and well-organized user group.

Access onto the Bay for kayaks and similar types of paddleboats is possible in at least six parks. High tide inundation and storm event flooding at mid-century will reduce paddleboating opportunities along this stretch of shoreline. In general, kayakers have the most flexibility among water sports enthusiasts in terms of capacity to use multiple types of launches, boat in various conditions and make use of launch sites that have been partially impaired. However, this is not true for persons with limited mobility or disabilities, who can only safely launch at a site that has been designed to accommodate their needs and is in good functioning condition (including access to the launch itself). Currently the Tidewater Boathouse at the Martin Luther King Jr. Regional Shoreline is the only location with an accessible launch. Other sites such as Crown Memorial State Beach, Estuary Park and additional locations in Martin Luther King Jr. Regional Shoreline provide relatively easy and safe access for launching onto the Bay in a kayak or similar type of paddleboat.

Only two locations, Estuary Park in the Oakland Estuary and Martin Luther King Jr. Regional Shoreline in San Leandro Bay, offer suitably calm conditions and the appropriate launch facilities needed for team rowing, or sculling. Both of these locations are likely to be exposed to storm flooding with 16 inches of sea level rise. The relatively new launch ramps, docks, and boathouse facilities at both sites are designed to accommodate higher tides and are constructed with resistant materials that will help prevent damage and allow the sites to recover quickly from flooding. During a recovery period, the two boating facilities may also benefit from their user groups – rowing teams that rely on the facilities for training – that would presumably have a strong interest in maintaining and restoring functions of the facilities.

Three of the parks addressed in the ART project area have public ramps for launching motorboats: Marina Park in Emeryville, Encinal Boat Ramp Park, and Martin Luther King Jr. Regional Shoreline. Higher daily high tides and flooding from storm events and wind waves are not likely to cause lasting damage to boat ramps because they are constructed to withstand exposure to Bay water. However, the length and slope of a launch ramp are designed specifically to allow for launching boats that are towed by a vehicle (without causing damage to the boat or vehicle). Depending on the design of the ramp and the site conditions, higher tides that cause longer periods of inundation could decrease the amount of time that the ramp is usable each day. The other public ramps in the project area likely face similar vulnerabilities due to sea level rise.

Fishing

Recreational fishing is allowed in the Bay with a fishing license from the California Department of Fish and Game. Popular fishing spots at seven fishing piers are found between Emeryville and San Leandro (though not all of these are located within parks). Fishing piers in Shorebird and Marina Parks in Emeryville and Middle Harbor Shoreline Park are unlikely to be exposed to tidal inundation or storm event flooding with 16 inches of sea level rise. In contrast, a loss of access and/or damage to fishing piers in Martin Luther King Jr. Regional Shoreline may occur due to storm event flooding by mid-century.

Depending on the communities that use the piers, the implications of losing access to specific piers will vary. For example, subsistence fishers might rely on having access to one or more piers in the project area and loss of these sites would significantly affect the wellbeing of these users. The project area may have some capacity to accommodate impacts to the fishing piers because fishers can seek out other access points; most parks in the project area allow fishing from the shoreline. Fishing in the ART project area is most likely to be affected by sea level rise impacts to the Bay Trail (which provides access to the shoreline and Bay for fishing) and water quality (e.g., due to sewage spills during periods of high tide and flooding).

Dog Recreation

Space for dog recreation is in high demand throughout the Bay Area. Of the parks assessed in the ART project, only Marina Park (in San Leandro) and San Lorenzo Park have fenced dog exercise areas; there are two additional dog parks on Alameda Island near Crown Memorial State Beach that are not addressed here. Most parks in the project area allow dogs on leash, with the exceptions of Point Emery, the beach at Crown Memorial, and the area south of Winton Avenue in the Hayward Regional Shoreline, where dogs are prohibited. Loss of designated dog exercise areas could lead to more violations of rules concerning dogs (e.g., leash laws and policies prohibiting dogs) in other park and recreation areas, and crowding in areas where dogs are allowed.

Restrooms

The ART project exposure analysis shows that with 16 inches of sea level rise, storm event flooding will likely affect half of the approximately 30 restrooms in the parks addressed in this chapter not including restrooms at golf courses. Flooding will lead to more frequent closures and additional repair costs for managing agencies. A few of the parks have portable toilet facilities. Flooding of these types of restrooms could harm water quality by releasing chemicals and human waste into the surrounding environment. Lack of restrooms could be an inconvenience for some visitors, and could deter others from visiting a park at all.

Parking

Many, if not most, visitors travel by car to the parks in the project area. Parking is essential to their ability to access the various recreation services and amenities provided. With 16 inches of sea level rise, a storm event would cause flooding in parking lots in more than a third of the parks: Marina Park (Emeryville), Crown Memorial State Beach, Martin Luther King Jr. Regional Shoreline, San Lorenzo Park, Gordon E. Oliver Eden Shores Park, Alden E. Oliver Sports Park, and Hayward Shoreline Interpretive Center. Parking areas in another six parks would potentially be exposed to wind waves during a storm event.

The sensitivity of each park to impacts on parking will depend on multiple factors. If flooding persists (e.g., due to poor drainage) or damages the lot (e.g., due to debris or erosion), parking areas might be closed for extended periods. Park use is usually higher on weekends and holidays, and flooding that affects parking areas during these times would have greater impacts on visitation and potentially on park revenues. Where flooding only partially compromises parking, there might be sufficient accommodation for the demand elsewhere within a park.

Alternatively, nearby on-street parking may allow people to use the park even when the parking area is closed. It is important to note that while these options provide some adaptive capacity, they would probably not address the needs of persons with limited mobility or wheelchair users who would essentially be prevented from accessing recreation services due to the lack of accessible parking spaces. Furthermore, while park managers can implement temporary 'fixes' for parking, they have less flexibility in making fundamental changes that would improve capacity to deal with impacts to parking areas. For example, their options could be limited by lack of funding and very specific requirements in plans and permits for amounts and types of parking in parks. Additionally, some neighborhoods may not allow parking for extended periods of time, and overflow parking could inconvenience residents.

Table 4. Summary of Recreational Activity Vulnerability. For recreational activities within each park, the vulnerability to high tide and storm events with 16 and 55 inches of sea level rise is summarized by the following categories: green indicates *no to low* vulnerability; yellow indicates *low to moderate* vulnerability; and red indicates *moderate to high* vulnerability.

Keys for the tables.

Parks and Recreation Areas
1. Point Emery
2. Shorebird Park
3. Marina Park, Emeryville
4. Middle Harbor Shoreline Park
5. Estuary Park & Aquatic Center
6. Shoreline Park, Estuary
7. Union Point Park
8. Encinal Boat Ramp Park
9. Crown Memorial Beach
10. Chuck Corica Municipal Golf Course
11. Shoreline Park, Bay-Farm Island
12. Martin Luther King, Jr. Regional Shoreline
13. Metropolitan Golf Links
14. Oyster Bay Reg. Shoreline
15. Marina Park, San Leandro
16. Marina Golf Course
17. Tony Lema Golf Course
18. Hayward Regional Shoreline
19. San Lorenzo Park
20. Skywest Golf Course
21. Hayward Shoreline Interpretive Center
22. Gordon E. Oliver Eden Shores Park
23. Alden E. Oliver Sports Park

Activity	**Icon**
walk/run/hike/bike (w)	
passive recreation (pr)	
facilities for groups/events (ge)	
sports fields/courts (sf)	
golf course (gc)	
nature/wildlife viewing (n)	
interpretive/education facilities (ie)	
swimming (s)	
paddleboating (pb)	
rowing (rw)	
sailboarding (sb)	
motorboat launch (mb)	
fishing (f)	
dog recreation (d)	
parking (p)	P
restrooms (r)	

Table 4. (con) Summary of Recreational Activity Vulnerability – 16 inches of sea level rise.

16" HIGH TIDE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
walk / run / hike / bike	green	green	green	green	green	green	green	green	green		green	green		green	green			yellow	green		yellow	green	green
passive recreation	yellow	green	green	green	green	green	green		green		green	green		green	green			yellow	green		yellow	green	green
group / event facilities					green							green							green				
sports fields / courts					green							green			green				green			green	green
golf course										red			green			green	green			green			
nature / wildlife viewing				green					yellow			yellow		green				yellow			yellow		
interpretation & education				green					yellow			green						green			yellow		
swimming	yellow								yellow														
paddleboating	yellow		green	green	green				yellow			green											
rowing					green							green											
sailboarding	yellow		green						yellow														
motorboat launch			green					green				green											
fishing pier		green		green	green						green	green						green					
dog recreation															green			yellow	green				
parking	green		green	green	green		green	green	green			green		green	green			green	green		green	green	green
restrooms			green	green	green		green	green	green		green	green		green	green			green	green		green	green	green

16" STORM EVENT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
walk / run / hike / bike	yellow	yellow	yellow	yellow	yellow	green	green	green	green		yellow	yellow		green	green			red	yellow		red	yellow	green
passive recreation	yellow	yellow	yellow	yellow	yellow	green	green		yellow		yellow	yellow		green	green			yellow	red		red	yellow	green
group / event facilities					yellow							yellow							yellow				
sports fields / courts					red							yellow			green				red			red	red
golf course										red			yellow			red	yellow			yellow			
nature / wildlife viewing				green					yellow			yellow		green				yellow			yellow		
interpretation & education				green					yellow			yellow						red			red		
swimming	red								red														
paddleboating	red		green	green	green				red			green											
rowing					green							yellow											
sailboarding	red		green						red														
motorboat launch			green					green				green											
fishing pier		yellow		green	yellow						yellow	yellow						green					
dog recreation															green			red	yellow				
parking	yellow		green	green	red		green	green	yellow			red		green	green			green	red		red	red	green
restrooms			green	green	yellow		green	green	yellow		yellow	yellow		green	green			red	red		red	red	green

Table 4. (con) Summary of Recreational Activity Vulnerability – 55 inches of sea level rise.

55" HIGH TIDE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
walk / run / hike / bike	R	Y	G	Y	R	G	G	G	R		R	R		G	G			R	R		R	R	R
passive recreation	R	R	G	G	R	G	G		R		R	R		G	G			R	R		R	R	R
group / event facilities					R							R							R				
sports fields / courts					R							G			G				R			R	R
golf course										R			Y			R	Y			R			
nature / wildlife viewing				Y					R			R		Y				R			R		
interpretation & education				G					R			Y						R			R		
swimming	R								R														
paddleboating	R		Y	G	R				Y			Y											
rowing					R							R											
sailboarding	R		Y						Y														
motorboat launch			Y					Y				R											
fishing pier		R		G	R						R	R						R					
dog recreation															G			R	R				
parking	Y		R	G	R		G	G	Y			Y		R	G			R	R		R	R	R
restrooms			G	G	R		G	G	R		R	R		G	G			R	R		R	R	R
55" STORM EVENT	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
walk / run / hike / bike	R	R	Y	R	R	Y	R	Y	R		R	R		Y	R			R	R		R	R	R
passive recreation	R	R	Y	R	R	R	R		R		R	R		G	R			R	R		R	R	R
group / event facilities					R							R							R				
sports fields / courts					R							R			R				R			R	R
golf course										R			Y			R	R			R			
nature / wildlife viewing				Y					R			R		Y				R			R		
interpretation & education				Y					R			R						R			R		
swimming	R								R														
paddleboating	R		Y	Y	R				R			Y											
rowing					R							R											
sailboarding	R		Y						R														
motorboat launch			Y					Y				R											
fishing pier		R		Y	R						R	R						R					
dog recreation															R			R	R				
parking	R		R	G	R		R	R	R			R		R	R			R	R		R	R	R
restrooms			R	Y	R		R	R	R		R	R		G	G			R	R		R	R	R

Individual Park and Recreation Areas

San Francisco Bay Trail: Segments from Emeryville to Hayward (Association of Bay Area Governments, Bay Trail Project)
This important recreation asset within the ART project area consists of 74 miles of existing and proposed trail between Emeryville and Hayward, which are part of a larger continuous regional trail system around the edge of San Francisco Bay. Recreational bicyclists, joggers, pedestrians, rollerbladers, people in wheelchairs, commute cyclists, bird watchers, parents with strollers, dog walkers, and many other users are found along the Bay Trail on a daily basis. The physical characteristics of the Bay Trail vary within the ART project area. Depending on its location, the Bay Trail consists of paved paths, dirt trails, bike lanes, sidewalks or signed bike routes. The Bay Trail functions as a shoreline recreational destination, a transportation corridor, and a setting for environmental education. In the ART project area, the Bay Trail links marinas, regional parks, city parks, a major commercial center, residential areas, an ecological reserve, wetlands, industrial areas, two interpretive centers, a boating center, a state beach, an observation tower, an international airport, two ferry terminals, and future access to a toll bridge pathway.

The existing physical and functional condition of the Bay Trail in the project area varies by location. The Bay Trail is maintained by the agency or private property owner responsible for the area where the trail is located. Agencies in the project area include: City of Emeryville, City of Oakland, Port of Oakland, City of Alameda, East Bay Regional Park District, City of San Leandro, Department of Fish and Game, and Hayward Area Recreation and Park District. Many of these jurisdictions are challenged with limited maintenance budgets for parks, open space and trails. Often, trash pick-up and weed abatement are taken care of while long-term maintenance of the trail including sweeping, resurfacing, etc. are typically put off until the trail no longer functions. Private land owners are also responsible for trail maintenance as required by BCDC development permits.

As discussed previously in this chapter, the Bay Trail is currently affected by flooding and portions of the trail have been temporarily closed or damaged due to extreme weather events. With 16 inches of sea level rise, a majority of the trail in the southern portion of the ART project area (i.e., south of Marina Park in San Leandro) would be affected by storm event flooding. With the notable exception of the Bay Trail around San Leandro Bay (in Martin Luther King Jr. Regional Shoreline), the majority of the trail in the northern portion of the ART project area is unlikely to experience significant impacts with 16 inches of sea level rise. In the longer term, most of the Bay Trail (along with almost all of the parks and golf courses) will be fully inundated or impaired by flooding with 55 inches of sea level rise.

The discussion of trail recreation activities in the previous section addressed the ways in which trails and paths would be sensitive to and have capacity to accommodate sea level rise impacts. Additional considerations for the Bay Trail in particular include the limited availability of funding for improvement, repair and maintenance of existing trails. Most capital funds are limited to new trail construction. Capacity to address impacts may be boosted by organized advocacy groups that support the Bay Trail (i.e., bicycle coalitions). These groups could mobilize, with the assistance of the Bay Trail Project, to push for Bay Trail repairs and improvements needed due to sea level rise. The combination of high sensitivities to impacts and relatively limited adaptive capacity suggest that the Bay Trail in the ART project area is quite vulnerable to future sea level rise.

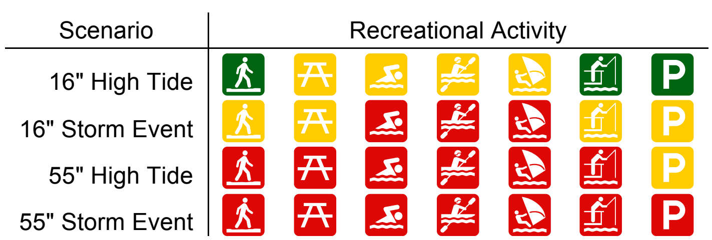
The consequences of impacts to the Bay Trail could be significant for a variety of reasons. Loss of Bay Trail functionality will result in a disruption of travel to jobs or school for those who commute by bicycle along the Bay Trail. The trail is also a tourist attraction, and closures would reduce expenditures in adjacent communities. For example, the Bay Trail passes through Jack London Square, serving as the primary promenade along the waterfront. Costs associated with ensuring a safe detour route for bicyclists and pedestrians and for repairing damaged trail segments will also have economic consequences for managing agencies.

Closures of the Bay Trail would result in losses of recreational capacity and shoreline access that are significant at multiple scales. Portions of the Bay Trail in the ART project area are easily accessed by low-income and/or underserved communities and function as their primary recreation destinations. In particular, trail closures will disproportionally affect households that do not own a car and rely on bicycling or walking as primary forms of transportation. Loss of shoreline access via the Bay Trail is a regional concern because the trail is the primary means of access to the largest area of open space in the region – San Francisco Bay. Throughout the project area, the capacity to provide most recreational services would be impaired by disruptions to the Bay Trail (both within and outside of parks). More frequent and costly damage to the Bay Trail will challenge agencies' capacities to maintain the sections of the trail for which they are responsible. Furthermore, responsibility for addressing damage to the Bay Trail could become confusing, and authorization for trail improvements or repairs, which involve several layers of government approval (possibly local, regional and state), could be difficult to accomplish efficiently in order to return the Bay Trail to a functioning status.

City of Emeryville (Department of Community Services)

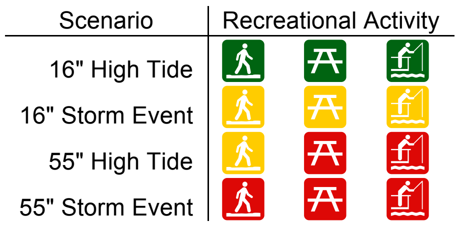
Point Emery

Point Emery Park is 1.4 acres with a small beach on its north side. It is a favorite site for accessing the Bay Trail and kiteboarding. The park would benefit from a new accessible path and replacement stairs to the beach. This park is rapidly eroding; more frequent flooding associated with higher Bay waters would accelerate this erosion. Maintaining this park would require expensive shoreline protection, which would not address the loss of the beach. The park is disconnected from inland neighborhoods, and, despite its popularity for kiteboarding, does not receive strong support from this or other user groups. For a key to the table that follows see Table 4 on page 12.



Shorebird Park

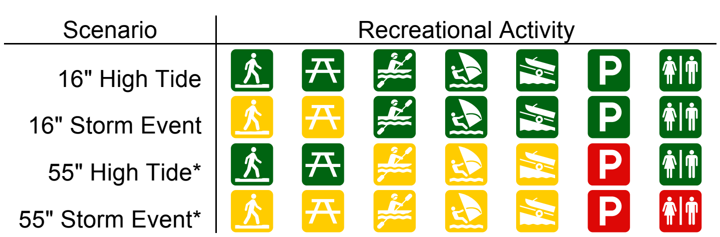
Shorebird Park consists of a viewing platform on piers contiguous to the Bay Trail. It includes a beach, a wooden dock with access ramps, and a connection to the Bay Trail. It is 2 acres, some of which is over water. The park is in fair condition, with the boardwalk, handrail, benches, paving, and some landscaping in need of replacement. These features can likely withstand more frequent flooding with minor additional impacts to their condition. However, as sea level continues to rise, Shorebird Park does not have space to be moved or expanded inland, and despite its popularity as a stopping point along the Bay Trail, the park does not have a community group that would be ready to advocate its protection. For a key to the table that follows see Table 4 on page 12.



Marina Park

This 13-acre park includes informal grass areas; ramps for windsurfing, motor boats and kayaks; picnic tables with grills; paths; a fire pit; parking; restrooms; and a sewage pumping station. The trails and street in the park are part of a Bay Trail spur. Marina Park is in fair condition. It has new paths and benches, and the grass areas, ramps, parking and rest rooms are in good condition. However, some landscaping needs to be replaced, many of the trees in the park are crowded and unhealthy, and accessible paths are needed to some picnic benches. Due to budget constraints, these improvements have been deferred. The majority of the park is unlikely to be exposed to significant flooding impacts with 16 inches of sea level rise. However, access to the park (along the Bay Trail and road) could be impaired by storm events under this scenario, and wind waves during storm events could potentially damage some paths and grassy areas, the restrooms, and the sewage pumping station. Temporary use of sandbags would help prevent damage to the restrooms and the pumping station.

With 55 inches of sea level rise, more than half of the parking area would be exposed to tidal inundation and storm event flooding and likely suffer damages. This amount of sea level rise would also reduce availability (each day) of the boat ramps due to higher tides. Under the 55 inch scenario, access to Marina Park as a whole would be limited or impossible due to the vulnerability of the road leading to it. Currently the park does not have a "friends of" organization, but it is very popular, has an adjacent residential population, and draws good turnout for annual California Coastal Cleanup events. For a key to the table that follows see Table 4 on page 12.



* Vulnerability ratings do not reflect likely vulnerability of the road that provides access to the park to impacts under these scenarios.

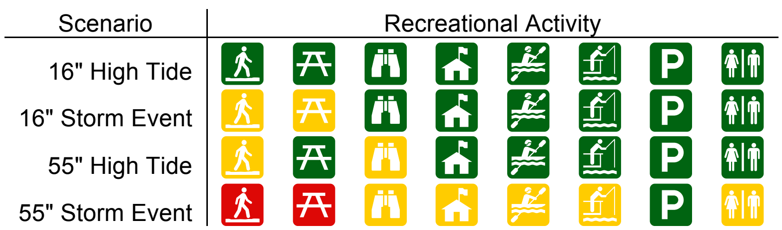
Port of Oakland

Middle Harbor Shoreline Park

Amenities and activities at this 38-acre shoreline park include more than two miles of pathways encircling Middle Harbor Basin; grass turf areas with picnic tables and barbeque pits; multiple restrooms; a sandy beach from which paddleboats can be launched; interpretive signage and maritime historic features (e.g., bollards once used for tying up ships and a viewing tower); nature and birdwatching opportunities; and iconic views of the Bay.

For the most part, facilities at this relatively new park are in very good condition. However, erosion of unpaved paths in the past (due to storm events) has caused enough damage to make them difficult to travel in a wheelchair. This park will likely be minimally affected by tidal inundation or storm event flooding with 16 inches of sea level rise, although wind waves could flood paths and some of the grass turf areas in the park, potentially requiring temporary closures and repairs. Substantially more of the park will be exposed to storm event flooding and wind waves with 55 inches of sea level rise.

These impacts could significantly impair trails and passive recreation amenities (e.g. grassy areas, picnic areas), and could reduce tidal habitat that provides wildlife viewing opportunities. Some of the interpretive features, such as the viewing tower and bollards, may be more resilient to storm event impacts. For a key to the table that follows see Table 4 on page 12.



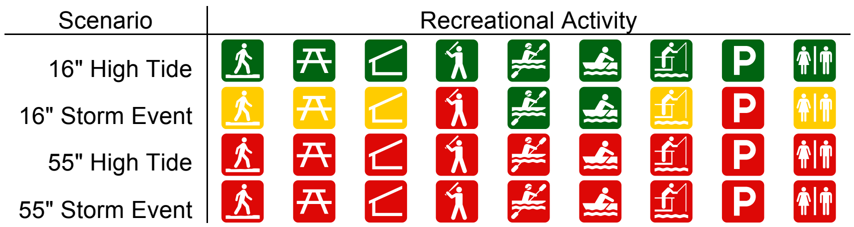
City of Oakland (Office of Parks and Recreation)

Estuary Park

Estuary Park and the Jack London Aquatic Center comprise a public rowing and visitor center, fishing hub, biking trail, boat launch ramp with boat trailer parking, a small-boat launching ramp, passive recreation, and ball field use facility. The rowing facilities are currently managed by the City of Oakland's Office of Parks and Recreation. However, the city is looking at opportunities for a non-profit organization to take over this role.

A large portion of this 12-acre park could be affected by storm event flooding with 16 inches of sea level rise. The relatively new launch ramps, docks and boathouse facilities at the site are constructed with salt resistant materials that will help prevent damage, and allow these uses of the park to be restored quickly after flooding. In contrast, the grass soccer field would certainly be damaged (or potentially destroyed) by salt water flooding.

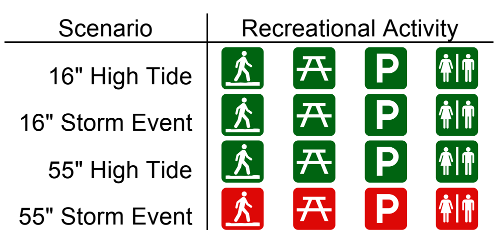
The rowing teams that rely on the facilities for training would likely provide some volunteer work and donations for restoring functions of the facilities if they were to be damaged. Loss of rowing opportunities at this site would affect underserved communities in Oakland. Teams' partnerships with community-based programs provide disadvantaged communities an opportunity to engage and experience these types of recreational activities. For a key to the table that follows see Table 4 on page 12.



Union Point Park

A small but popular community park on the Oakland Estuary, Union Point Park is an example of green remediation, for which contaminated soils from the site were encapsulated under a large lookout hill that is a signature feature of the park. This seven-acre park also has a restroom, children's play structure and picnic tables. Heavy park use and frequent permitted events, coupled with reduced staffing levels for maintenance (due to budget cuts in the City of Oakland) have impaired the physical condition of the park.

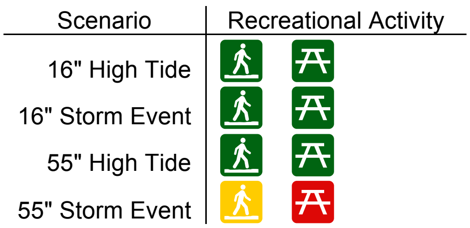
The park would likely experience impacts from wind waves during storm events with a 16 inch sea level rise, but due to its elevation, it is unlikely to be exposed to significant flooding. Even with some flooding, the park would probably recover quickly. The park is tied directly to the City of Oakland's storm drain system to facilitate drainage of excess water, and it is equipped with an underground sump filtration system. Furthermore, the park's design and sturdy structures make it resistant to saltwater damage. With 55 inches of sea level rise, storm event flooding and wind waves will likely affect the majority of the park and amenities, including paths, picnic tables, play structure, lawn areas and restrooms. For a key to the table that follows see Table 4 on page 12.



City of Alameda (Recreation and Park Department)

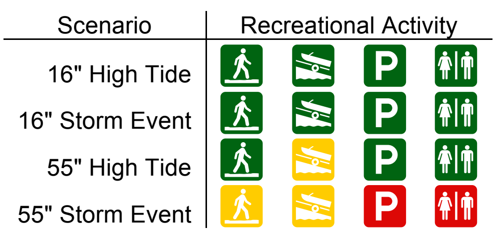
Shoreline Park, Estuary

This 5-acre park on the Oakland Estuary includes 0.7 miles of Bay Trail and a lawn area for passive recreation. The park has little or no exposure to storm event flooding and tidal inundation with 16 inches of sea level rise. With 55 inches of sea level rise, much of the park would be exposed to storm event flooding. The saltwater exposure could damage the Bay Trail and destroy the grass area. For a key to the table that follows see Table 4 on page 12.



Encinal Boat Ramp Park

The primary recreation feature in this approximately seven-acre park on Bay Farm Island is a motorboat launch. With 16 inches of sea level rise, the entire ramp will be exposed to storm event flooding and wind waves. These impacts are unlikely to cause lasting damage because the ramp is constructed to withstand exposure to Bay water. Only a very small portion (3%) of the entire park area is projected to be affected by higher tides with 16 inches of sea level rise. However, higher tides may decrease the amount of time that the ramp is usable each day. For a key to the table that follows see Table 4 on page 12.

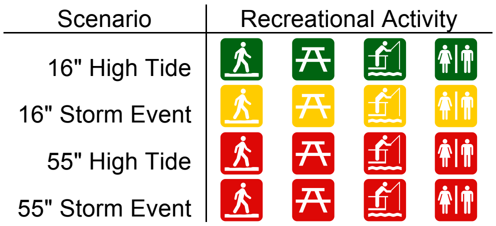


Shoreline Park, Bay Farm Island

This 32-acre park forms a narrow band along the northeastern and western edge of Bay Farm Island. A 2.5-mile stretch of Bay Trail, iconic views of the Bay, a fishing pier, lawn areas, and reservable picnic facilities make this a popular park for walking, running and biking, passive recreation, and family/group gatherings. Exposure mapping indicates that the park has low exposure to tidal inundation and storm event flooding with 16 inches of sea level rise, but that wind waves are likely to overtop the riprap shoreline protection around this park. During winter storms Shoreline Park has experienced erosion that would likely worsen with sea level rise. (The city is working with the Army Corps of Engineers to fund a reinforcement project to address this erosion issue.) Temporary flooding due to wind-waves is unlikely to cause lasting damage to the Bay Trail and picnic facilities, but lawn areas may be damaged and, with repeated saltwater exposure, unable to re-grow.

With 55 inches of sea level rise most of the park, along with Bay Farm Island would be severely flooded during a storm event. A high tide with 55 inches of sea level rise would inundate the north shore of the park, which includes a fishing pier, parking and access to the park from a wooden footbridge (owned and maintained by East Bay Regional Park District) across San

Leandro Channel. Water already reaches the bottom of the bridge support beams during extreme high tides. For a key to the table that follows see Table 4 on page 12.



East Bay Regional Park District (EBRPD)

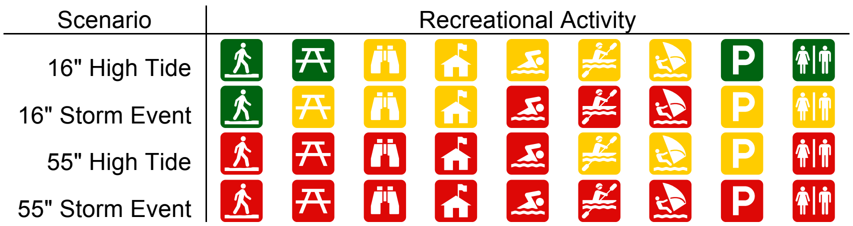
Crown Memorial State Beach

Crown Memorial State Beach on Alameda Island is comprised of approximately 70 acres of sandy beach and 25 acres of landscaped areas. The northern portion of the park is owned by California State Parks and includes the Crab Cove Visitor Center. The long narrow southern part, the beach and trail along Shoreline Drive, is owned by the City of Alameda. East Bay Regional Park District has operating agreements and manages both areas as one park. The State of California and the City of Alameda do not provide funding except for a shared cost for annual beach maintenance. The park's long sandy beach – the largest contiguous beach on San Francisco Bay – is a popular recreational feature. Some flooding impacts are already evident at the park. The rocky point at the northern tip of the park is frequently overtopped with high tides and wind waves; and the lawn outside of the Crab Cove Visitor Center was flooded in January 2006 during an extreme high tide on New Year's Day.

The ART project exposure analysis suggests that while much of the park will not be affected by flooding with 16 inches of sea level rise, more frequent flooding in some portions of the park will reduce access (until flood waters recede) to picnicking facilities, grassy areas, and the beach. Furthermore, storms may cause lasting damage to grassy areas (due to saltwater exposure) and the beach (due to erosion). Higher daily tides will reduce the amount of time that the wheelchair-accessible Tide Ramp is available for use by school groups and members of the public. Elevated groundwater and salt water intrusion could harm trees, grass and other landscaped features. The two main structures at the park – the Crab Cove Visitor Center and the park service yard building – are raised and, due to their construction, would dry out rapidly after a flood event.

As discussed previously in this chapter, the approach to exposure mapping used in this assessment is not appropriate for dynamic systems such as beaches. Managers familiar with the park report that the beach is eroding and would likely be susceptible to greater erosion with higher high tides and flooding with 16 inches of sea level rise. Loss of this unique beach would affect access for swimming, wading, sunbathing, boardsailing and paddleboating, and would be significant loss to the Alameda community and the entire Bay Area. The beach is periodically re-nourished, and this historical practice could expedite future nourishment after storm events that significantly erode the beach.

Sea level rise impacts could challenge the governance of Crown Memorial. With widespread flooding impacts, inter-agency coordination could become strained, and East Bay Regional Park District could be forced to give lower priority to recovery efforts at Crown Memorial as staff is focused on properties that the District owns and manages. For a key to the table that follows see Table 4 on page 12.



Martin Luther King Jr. Regional Shoreline
This popular, 217-acre park, located along the shoreline around San Leandro Bay, offers a diversity of recreation opportunities. Park facilities and activities include 3.7 miles of Bay Trail with six bridges, the Tidewater Boating Center with facilities and launches for rowing and paddleboats, a boat launch ramp, the Shoreline Center (meeting facility), 16 acres of grass turf, nine staging areas providing parking, picnic tables and restrooms, a staff office, the Arrowhead Marsh Overlook ramp and boardwalk, interpretive signage, wildlife viewing opportunities, and three marshes – Arrowhead, New, and Damon – which provide habitat for endangered species. Tidal inundation and storm event flooding with 16 inches of sea level rise is likely to affect much of the park – including many of the park amenities.

In the past, flooding has occurred on lawns and the Bay Trail during extreme weather events that coincided with high tides. High tides (greater than 6 feet) also flood the marshes regularly, and, when combined with surge, can affect the Tidewater Boating Center. Currently, the park assets recover quickly or are not significantly impaired by these impacts. For example, despite regular flooding, the three marshes are not subject to erosion due to the presence of upper tidal plants.

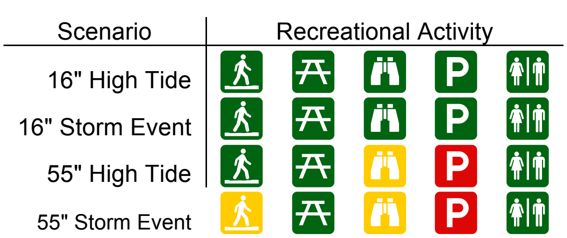
Use of the Bay Trail can be restored quickly once flooding recedes and debris left by storms is removed. With more frequent storm event flooding and/or tidal inundation due to sea level rise, lawn areas might not recover from repeated saltwater exposures. Damage to the Bay Trail, which is paved along most of the shoreline, would be unlikely, but extended closures would be necessary with flooding that persists longer. Longer inundation of the marshes could diminish the survival of endangered clapper rails and salt marsh harvest mice that can only utilize the habitat when the marsh is exposed during low tides. Other shorebirds are also forced to find other refuge areas when the marshes are flooded, and with sea level rise more inundation will reduce opportunities for birdwatching. Sixteen inches of sea level rise will also cause impacts in previously unaffected areas of the park. Storm event flooding might cause temporary closures of many of the parking lots, picnic areas and restrooms. Park managers note that structures like the Tidewater Boating Center, the Shoreline Center and staff offices would take a long time to reopen after flooding.

Some park assets have functional capacity to accommodate higher Bay waters. For example, the Tidewater Boating Center is in good condition and has a dock that rises with the tides and was built for a higher tide than 55 inches. Additionally, restoration of the shoreline and Arrowhead Marsh over the past decade has improved the resilience of these habitats to storm events and high tides. The most significant source of adaptive capacity for the park comes from EBRPD's strong partnerships with organizations that implement restoration, education, and stewardship programs at the site. Save the Bay and Golden Gate Audubon bring in thousands of volunteers for thousands of hours to plant, maintain, and improve the marshes (e.g., more than 5,000 volunteers worked more than 16,000 volunteer hours in 2011). Most of the educational programs are offered to schools in the underserved areas of Oakland and Alameda County. The Invasive Spartina Project and several agencies provide funding for and implement restoration of the marshes and shoreline while eradicating the *spartina alterniflora* (Atlantic Cord Grass) in the marshes and creeks.

Efforts to improve the park's resilience may be slowed by cumbersome planning and permit processes, as well as the overlap of ownership and jurisdictions along the San Leandro Bay shoreline. Vulnerability of the Martin Luther King Jr. Regional Shoreline also has implications for surrounding areas. Four creeks that run through the park before draining into San Leandro Bay must be free from debris and *spartina alterniflora* in order to convey stormwater that would otherwise flood Oakland communities during high tides and storms. For a key to the table that follows see Table 4 on page 12.

Oyster Bay Regional Shoreline
This 190-acre park, located on a former landfill in San Leandro that closed in the 1980's, is still under construction. Some park amenities are already open to the public, including a segment of the Bay Trail along the shore as well as upland trails, picnic tables, a restroom, and a 4-acre grass area. Due to its relatively high elevation, the park is not exposed to much flooding with sea level rise. However, the lower Bay Trail segment along the shoreline might be affected by storm flooding with 55 inches of sea level rise. The impacts would likely be temporary (e.g., closures until flood water recedes and debris is removed) rather than permanent because this portion of the Bay Trail is mostly paved.

Streets surrounding the park could experience sea level rise-related flooding sooner than Oyster Bay Regional Shoreline because they are lower in elevation, and they drain into the adjacent San Leandro Slough and marsh, which might not have capacity for increased flood flows. In turn, this might cause longer-lasting disruptions to access to the park. Higher and more frequent inundation of the adjacent slough and marsh could also diminish the quality of opportunities for wildlife viewing, which is currently a popular activity at the park. To fully convert the landfill to a park over the next few years, EBRPD will be completing grading and landscaping and a new park entrance at Davis Street, with new parking located within the park. Higher Bay water levels are being factored into the design of these improvements to reduce exposure to sea level rise impacts, which enhances adaptive capacity. For a key to the table that follows see Table 4 on page 12.

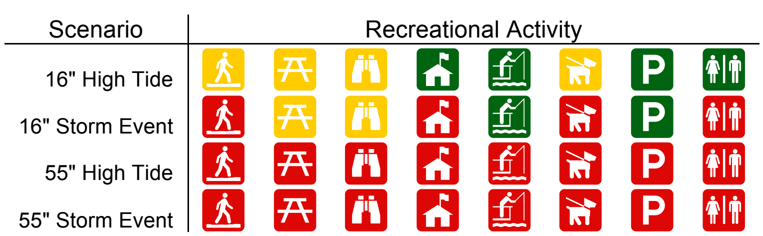


Hayward Regional Shoreline

This large, 1700-acre shoreline park features five miles of unpaved Bay Trail (along the park's outboard levees) and other levee-top trails that connect the shoreline trail from San Leandro to the Hayward Shoreline Interpretive Center (just north of Highway 92). The park is popular for walking, biking, running, bird watching, dog walking, picnicking, fishing, and enjoying scenic views. It also provides opportunities to see three different marshes. Oro Loma Marsh, near the northern end of the shoreline, is a tidal salt-water marsh at its western end, and a seasonal freshwater marsh fed by rainwater at the slightly higher elevations at its eastern end. Cogswell Marsh, near the southern end of the shoreline, was formerly a commercial salt pond that has been restored to tidal salt marsh habitat. Hayward Marsh is also a restored marsh, but it supports a different, more brackish mixture of vegetation because it receives treated freshwater from a nearby wastewater treatment plant (Bay Nature 2012).

Recreational services at the park could be impaired by shoreline access impacts (including the Bay Trail, other levee trails, and parking areas), as well as the wetlands habitats. Currently, high tides, storm flooding, and strong winds occasionally cause waves to overtop outboard levees, leaving the Bay Trail unusable until flooding recedes and debris can be removed, if necessary. Analysis of sea level rise scenarios suggests that with 16 inches of sea level rise, the Hayward Regional Shoreline will experience significant exposure to high tide inundation and storm event flooding. These impacts will exacerbate flooding of the Bay Trail leading to more frequent closures. The Bay Trail within this park is especially susceptible to impairment because disruption of a small portion of trail would likely require closure of a large trail segment.

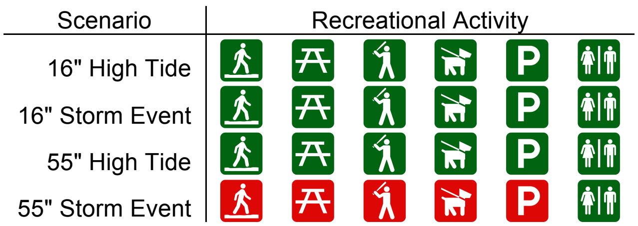
Beyond the recreational impacts, more frequent flooding and higher tides will destabilize levees, which are already in need of repair, and potentially cause uncontrolled flows into the marshes, which would also necessitate closure of the park. Further, these impacts could impair the marsh capacity to receive treated wastewater from Union Sanitary District and damage infrastructure such as the PG&E distribution and transmission lines and a railroad line that run through the park. In the event of a disruption to the levees (and Bay Trail), the top priority for park managers is to repair the internal and outboard levees to avoid being in violation of their Regional Water Quality Control Board permit for operation of the Hayward Marsh. Thus, the restoration of recreation activities at the park is linked directly to the condition of the levees and resources available to maintain them. Lack of funding and difficulties obtaining permits have already delayed maintenance and led to levee failure. In contrast to the levees, the marshes are likely to be more resilient to flooding and inundation impacts. Over time, however, longer periods of inundation and changes to the habitat condition will reduce the amount and quality of wildlife watching opportunities. For a key to the table that follows see Table 4 on page 12.



City of San Leandro (Department of Recreation and Human Services)

Marina Park

Marina Park in San Leandro features approximately 1 mile of paved Bay Trail, picnic and playground facilities, lawn areas, and a sand volleyball court. Very little of this 30-acre park would be exposed to tidal inundation or storm flooding with 16 inches of sea level rise. The sea level rise mapping analysis indicates that a significant portion of the park is exposed to wind waves under this scenario. However, the park is within a protected lagoon, so this impact might not occur. With 55 inches of sea level rise, almost all of the park would be exposed to storm flooding, resulting in park closures and potentially causing significant damage to the Bay Trail, lawn areas, playground facilities, sand volleyball court, and parking area. For a key to the table that follows see Table 4 on page 12.



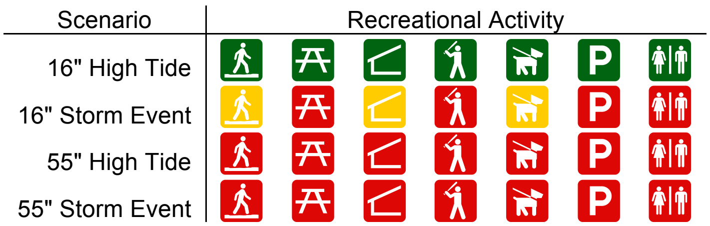
Hayward Area Recreation and Park District (HARD)

San Lorenzo Community Park

This heavily used, 31-acre park is adjacent to marshland on its western property line. The park has three baseball fields, two basketball courts, one turf and two grass soccer fields, a playground, dog park, parking lot, community building (8,236 sq. ft), two exterior restroom/snack bar buildings, and a pond. The property has a number of existing issues including flooding of the western ball fields during heavy rains due to slow drainage into the adjacent marsh, and limited maintenance funding. Sixteen inches of sea level rise will likely cause storm event flooding to occur over much of the park, which will damage and potentially destroy grass areas and landscaping and cause temporary closures of other facilities (e.g., artificial fields, sports courts and buildings). This will reduce revenues from field fees and building rentals, and increase repair and maintenance costs.

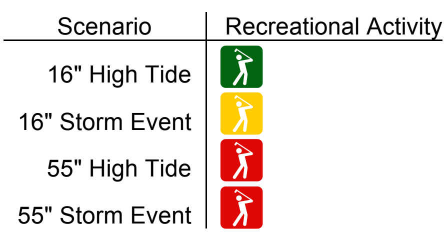
Elevated groundwater will damage pavement and building foundations, and saltwater intrusion will have impacts on landscaping and the well water used for irrigation. This park is the only community park in San Lorenzo, which has a very high population of senior citizens that use the community center at the park. Any loss of programs will significantly affect this group because there are no nearby senior centers. Loss of low cost sports or other recreational opportunities will affect low-income residents who may not have the means to travel to distant facilities.

Despite strong community interest in the park, there is little that the managing agency, Hayward Area Recreation and Park District (HARD), can do to raise revenues for adaptive measures. HARD is working to develop a new master plan for the park, which will provide an opportunity to consider and address current and future flooding problems. For a key to the table that follows see Table 4 on page 12.



Sky West Golf Course

This 125-acre, 18-hole course provides the Hayward area with a public golf course, which has a restaurant, pro shop, a banquet area, and maintenance buildings. With 16 inches of sea level rise, the course would have relatively low exposure to storm event flooding. However, the western portion of the golf course currently floods during heavy rains when water cannot drain rapidly into the adjacent marshlands to the west. This portion of the golf course must be closed several days per year during storm events, and the revenue lost cannot be replaced. Even with a small increase in Bay water levels, this drainage problem will be exacerbated, causing a greater portion of the golf course to be impaired for longer periods of time. The grass turf will also be sensitive to higher groundwater and saltwater intrusion. To better cope with drainage/flooding issues, a dike would need to be built with pumps, or the land would need to be raised, neither of which are low cost solutions. If the impacts preclude opportunities to play 18 holes, it is possible that the course could be redesigned as a 9-hole course, which would allow it to remain open but would significantly reduce revenues. Opportunities to increase revenues are limited because this golf course cannot compete well at higher prices. For a key to the table that follows see Table 4 on page 12.

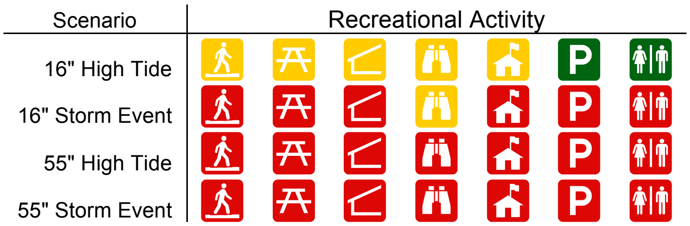


Hayward Shoreline Interpretive Center

This 4,180 square foot educational and resource center introduces grade school groups and adults to the ecology of San Francisco Bay. The center is not currently affected by storm impacts, and during recent king tide[1] events the center (which is on stilts above the salt marsh) had approximately 6 inches of clearance. Exposure to sea level rise impacts would occur first with storm event flooding. Occasional flooding of the Center could be addressed with temporary corrective measures such as pumping, but more frequent flooding from storm events or high tide inundation would cause structural damage. The building cannot be relocated, though it might be possible to further elevate it, cost permitting, and assuming that access to the facility could be maintained. HARD works closely with the Hayward Shoreline Planning Agency and

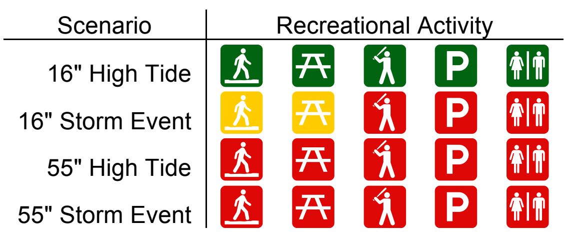
[1] A king tide is an extreme high tide event that occurs when the solar and lunar gravitational forces reinforce one another at times of the year when the moon is closest to the earth.

their Citizens' Advisory Committee, which would offer political support for addressing these issues at the center. For a key to the table that follows see Table 4 on page 12.



Gordon E. Oliver Eden Shores Park of Hayward

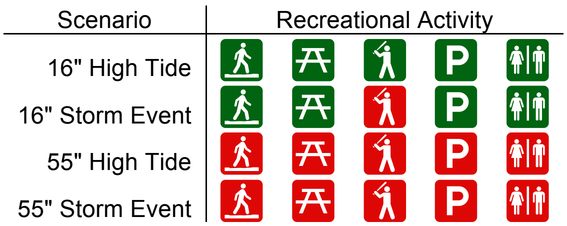
This 5-acre park has three tennis courts, a basketball half-court, a grass soccer field, a parking lot, open grass areas, picnic tables, and a restroom. With 16 inches of sea level rise, wind waves may overtop levees, leading to flooding in the park that would significantly damage the grass areas. Higher groundwater levels and saltwater intrusion could damage landscaping, pavement, and foundations of structures. Poor drainage from the park into the adjacent marsh channel during storm events could be exacerbated by higher Bay water levels. The synthetic court surfaces will be less affected because they can withstand saltwater exposure without experiencing lasting damage, but they would still require time to drain. All of these impacts would lead to more closures and repair costs. In most cases, if the park is only partially impaired by flooding or other impacts, managers would only need to close the affected areas. For a key to the table that follows see Table 4 on page 12.



Alden E. Oliver Sports Park of Hayward

This 25-acre sports park contains two artificial turf soccer fields, one grass soccer field, four baseball fields, two snack bars/restroom buildings, a play area, picnic area, basketball area, and two parking lots. With 16 inches of sea level rise, storm event flooding and wind waves might overtop levees surrounding this park, leading to flooding that would significantly impair the grass playing fields. Flooding might also occur during heavy rains because the site would not drain well into Alameda Creek when the creek is elevated due to higher Bay water levels. Elevated groundwater as well as saltwater intrusion could damage landscaping, pavement, and foundations of structures. The synthetic turf fields and the sports courts will be less affected because they can withstand saltwater exposure and higher groundwater levels without experiencing lasting damage. However, these playing areas would still require time to drain after flooding.

All of these impacts would lead to more closures and repair costs and reduce income generate by the field fees. As it is, the income for the sports park cannot be increased. In most cases, if the park is only partially impaired by flooding, managers would only need to close the affected areas, allowing them to maintain some revenues during periods of recovery. For a key to the table that follows see Table 4 on page 12.



Consequences

The potential consequences of the climate impacts are considered for the parks and recreation system as a whole. Consequences are the magnitude of the effects on the economy, society, environment, and governance if an impact occurs. Factors that inform the magnitude of the potential consequences include the severity of the impact on operations and maintenance or capital improvement costs, the size and demographics of the population affected, the types of natural resources affected, and the type, extent, and severity of the effects on humans and the environment.

Over time, sea level rise impacts will lead to significant negative consequences for many of the recreational services provided by parks and golf courses in the ART project area. Storm event flooding associated with 16 inches of sea level rise is likely to cause the majority of disruptions to these services. With 55 inches of sea level rise, recreational services in parks around San Leandro Bay and along the Hayward shoreline will be completely lost due to impacts of high tide inundation and storm events.

<u>Economy</u>
Economic consequences of these impacts identified by park managers include large increases in maintenance and repair costs; loss of revenues during closures; high costs of possible adaptive strategies (e.g., new shoreline protection and retrofits to structures); and loss of jobs if parks are shut down. Additionally, Bay Trail closures would disrupt travel to jobs and schools. Economic consequences of sea level rise in any one park within the project area are unlikely to be significant to the region. However, the cumulative costs of added maintenance and repair, expensive retrofits, and lost revenues and jobs throughout the project area will take their toll on local and regional economic growth if parks are no longer able to effectively contribute to improving the quality of life and aesthetic characteristics of the area, and attracting businesses and generating jobs.

A valuation analysis for eight of the parks in the project area provides an additional indication of the economic consequences of the loss of parks and recreation areas. The eight parks studied were (1) Crown Memorial State Beach, (2) Hayward Regional Shoreline, (3) Martin Luther King, Jr. Regional Shoreline, (4) Oyster Bay Regional Shoreline, (5) Estuary Park (including the Jack London Aquatic Center), (6) Union Point Park, (7) Marina Park (in San Leandro), and (8) the Hayward Shoreline Interpretive Center and trails. The value of the total loss of these eight parks, including all amenities and uses, at mid-century is almost $190 million (in today's dollars). This value takes into account the replacement costs for major structures (e.g. an interpretive center, a boathouse), the loss of revenues (e.g. from field rentals), and the value of loss of recreational activities. It is likely that the actual value would be greater; this analysis does not take into account the costs to replace all park infrastructure (e.g. roads, parking areas, picnic facilities, etc.) and conservative approach was used in estimating the value of recreation activities. (Refer to the appendices for the full report and methods used in this valuation analysis.)

Society
Reduced opportunities for recreational services across many parks for underserved populations (e.g., persons with disabilities, seniors, and low-income residents), as well as disruptions to specific parks that serve the needs of these populations, could have significant societal consequences. Bay Trail manager Laura Thompson points out "closures to the Bay Trail would disproportionately affect households that do not own a car and rely on bicycling and walking as primary forms of transportation." A recurring issue is the disproportionate impairment of access and recreation opportunities for persons with limited mobility and wheelchair users. These park visitors are much less likely than other user groups to be able to use trails, boat launches, parking areas, and picnic and other facilities that are partially impaired by flooding. Within any one park, this issue might not be significant, but the cumulative effect is that persons with limited mobility will have much less access to the shoreline and recreational services.

Disruptions to San Lorenzo Park illustrate how impacts to a specific park can have critical societal consequences. Karl Zabel, an operations supervisor with the Hayward Area Recreation and Park District notes, "[s]torm flooding/inundation will have a large impact on the recreational opportunities, since this is the only community-sized park in San Lorenzo. San Lorenzo has one of the highest senior citizen populations. This population uses many of the senior programs at the Community Center and any loss of programs will impact this population since there are no nearby Senior Centers. The population of San Lorenzo has a number of underserved residents that will be impacted if low cost sports or other recreational opportunities are lost, since this population does not always have the means to travel to distant facilities."

Consequences of park closures could also be serious for low-income residents living near parks who rely on these free, easily accessed sites for family gatherings, weekend recreation, and sports activities. Similarly, popular educational and stewardship programs at Martin Luther King Jr. Regional Shoreline are primarily offered to schools in the underserved areas of Oakland and Alameda County. The communities that use these parks and participate in these programs are unlikely to have other, similar opportunities to recreate near, learn about, and connect with the Bay.

Marina Park in Emeryville serves as another example. The sewage pump station on the peninsula serves both the park and the marina, which is believed to be home to low-income, live-aboard tenants whose boats do not all have toilets on board. Flooding damage to the pump station would leave these residents without access to proper sanitation, causing public health issues at the park and marina.

A 2006 analysis of recreation demand by BCDC staff suggests that demand for Bay Area water-oriented recreation has grown and will continue to grow due to factors such as population growth, an aging population, and an increase in ethnic diversity (BCDC 2006). Already, specific communities within the project area, such as the Fruitvale neighborhood in Oakland, are underserved in terms of access to parks. These conditions – existing unmet needs and growing demand for recreation – suggest that cumulative loss of shoreline access and recreation opportunities due to closures of multiple parks in the project area would have significant societal consequences. This overarching consequence is somewhat muted because when exposed to impacts with 16 inches of sea level rise, most parks will be able to remain open even if they are partially impaired, except during periods of recovery from storm events. However, with 55 inches of sea level rise, all but one park and two golf courses would be unlikely to continue to function, meaning that they would not provide recreational services to any users.

Environment

The environmental consequences of sea level rise impacts vary depending on the park setting and recreational services. Crown Memorial State Beach, Martin Luther King Jr. Regional Shoreline, and the Hayward Regional Shoreline and Interpretive Center each provide opportunities for interpretation, education, and wildlife and nature viewing that are unique and regionally significant, and they serve to protect the regionally significant environmental resources (e.g., endangered species, fragile habitats, and ecosystem services) at each site. Clearly, loss of these habitats and species would have significant environmental consequences. Though it is less obvious, disruption of the recreational services at these parks would also have a significant environmental consequence. Engaging Bay Area residents through interpretation, education, and wildlife and nature viewing is essential for building awareness and support for environmental protection. In more developed portions of the project area that do not support significant natural resources, impacts to parks and recreation areas will have fewer consequences for the environment.

Governance

With 16 inches of sea level rise, it is possible that almost all parks addressed in the ART project assessment will have some exposure to storm event flooding. This is a drastic increase in flooding exposure compared with current conditions, and it will have significant governance consequences. The likelihood is very high that after storm events, managing agencies will regularly be faced with extensive damage to multiple parks that they operate. Agencies will have to prioritize recovery efforts, and as Anne Rockwell, Shoreline Unit Manager for the East Regional Park District, notes, this may strain relationships between agencies that co-own and/or manage a park if priorities for recovery differ. Sea level rise impacts may change the management needs at some parks (e.g., towards an approach that focuses on disaster preparedness and response); to accommodate such shifts in management demands, agencies might need to hire differently trained staff and reallocate funds. As agencies try to adjust to new conditions in the parks, they may have difficulties obtaining permits for adaptive management strategies that are not addressed in existing environmental and building regulations and policies. Even if these issues related to management responsibilities and priorities do not emerge as serious challenges, the dramatic increase in required maintenance and repair will have significant consequences for the agencies' capacity to continue to provide recreation services in the project area. This expense could also affect their ability to maintain services in other parks in their service area outside of the project area.

Key Findings

The park and recreation facilities and services within the subregion include beaches, grassy areas, picnic areas, playing fields, local and regional trails (including the Bay Trail), golf courses, wildlife viewing areas, fishing areas, boat docks, passive recreation areas, and interpretive centers. The most common activities within these recreation facilities include walking, biking, passive recreation, and dog recreation. Overall, park and recreation facilities and services are moderately vulnerable to storm event flooding with 16 inches of sea level rise, and very vulnerable to the daily high tide with 55 inches of sea level rise.

Few of the parks and recreation facilities are exposed to the daily high tide with 16 inches of sea level rise, with the exception of wildlife viewing. Some of the tidal marshes will likely be submerged for longer periods of time by the daily high tide with 16 inches of sea level rise, and this will reduce opportunities for wildlife viewing. The number of park and recreation facilities and services that may be exposed to 16 inches of sea level rise increases with storm event flooding. These include the recreation areas around San Leandro Bay, along the Hayward shoreline, the beaches at Crown Memorial State Beach in the City of Alameda, Point Emery in Emeryville, and parking and restrooms in half of the parks within the subregion. Additionally, a majority of the shoreline trails, paths within parks, picnic areas, beaches, grassy areas, and other landscaped features that support the most common activities at the park sites will be exposed to storm event flooding with 16 inches of sea level rise.

The majority of parks and recreation facilities, including golf courses within the subregion, will be exposed to high tide inundation and storm event flooding with 55 inches of sea level rise. Only a few parks, including Middle Harbor Shoreline Park in the City of Oakland and Marina Park in San Leandro would retain their recreation functions with 55 inches of sea level rise.

The recreation uses and services that are most sensitive to the effects of sea level rise and storm event flooding include trails designed for people with limited mobility, unpaved trails close to the shoreline, the beaches at Crown Memorial State Beach, and grassy areas. People with limited mobility will find it more difficult to move through and detour around inundated and storm damaged areas. Unpaved trails located close to the shoreline will be subject to erosion, flooding, and storm damage that may wash away portions of the trail. Grassy areas are highly sensitive to salt water and many have poor drainage. The beaches at Crown Memorial State Beach are already eroding and require replenishment. Climate impacts such as sea level rise coupled with a storm event will likely increase and accelerate this loss.

Some of the functional roles that shoreline parks and recreation areas serve in the subregion may be replicated at other park sites. Inland parks and recreation sites may provide some of the same functions such as playing fields, jogging trails, passive recreation, and picnic areas. Other functions, however – such as swimming, wading, boardsailing, paddleboating, aquatic wildlife viewing, and shoreline interpretation – are uniquely tied to the shoreline and would not be available within the subregion if lost or significantly damaged due to tidal inundation and storm event flooding. Additionally, the loss of any of these shoreline parks would increase the crowding and overuse that is already experienced at some parks.

The adaptive capacity within the subregion will vary depending upon the characteristics of each site and its recreational activities. For trails and pathways, maintenance and operations – including temporary closures and re-routings – may be possible even with storm event flooding and 16 inches of sea level rise. For some of the most sensitive uses and recreation sites, such as access for people with limited mobility and wildlife viewing, adaptive capacity may be low even at 16 inches of sea level rise, especially with storm event flooding. With 55 inches of sea level rise, particularly with storm event flooding, the adaptive capacity for most recreation sites and uses will not be sufficient to maintain park facilities and functions.

References

Bay Nature. Undated. Hayward Regional Shoreline. http://baynature.org/places/hayward-regional-shoreline.

Hou, J., M. Rios. 2003. Community-Driven Place Making. The Social Practice of Participatory Design in the Making of Union Point Park. Journal of Architectural Education. 57:1. Pp. 19-27.

San Francisco Bay Conservation and Development Commission (BCDC). 2006. Staff Report. Recreation and San Francisco Bay.

Stralberg, D., M. Brennan, J. Callaway, J. Wood, L. Schile, et al. 2011. Evaluating Tidal Marsh Sustainability in the Face of Sea-Level Rise: A Hybrid Modeling Approach Applied to San Francisco Bay. PLoS ONE 6(11): e27388.

Veloz, S., N. Nur, L. Salas, D. Stralberg, D. Jongsomjit, J. Wood, L. Liu, and G. Ballard. 2012. San Francisco Bay Sea-Level Rise Website. A PRBO online decision support tool for managers, planners, conservation practitioners and scientists. Phase II report to the California State Coastal Conservancy. http://data.prbo.org/apps/sfbslr/PRBOCoastalConservancyTechnicalReport.pdf.

Chapter 9. Airport

Oakland International Airport (OAK) is located in the ART project area approximately 6.5 miles southeast of downtown Oakland on Bay Farm Island (Figure 1). It first opened to commercial aviation in 1927, and is currently one of three airports in the San Francisco Bay Area operating international passenger service; the other two are San Francisco International Airport (SFO) and Norman Y. Mineta San Jose International Airport (SJC).

OAK is owned and operated by the Port of Oakland (Port), which is an autonomous department of the City of Oakland that receives no tax money from the city and funds its own operations. The Port is governed by a Board of Port Commissioners, nominated by the mayor of Oakland and appointed by a vote of the Oakland City Council. The Port manages property stretching along 20 miles of the eastern shore of San Francisco Bay and is divided into three operating units: Aviation, which owns and operates Oakland International Airport; Maritime, which owns and operates the Port of Oakland; and Commercial Real Estate, which owns development property along the shoreline, including the Jack London Square District.

Figure 1. Oakland International Airport area map. (Source: Google 2012)

OAK encompasses 2,600 acres and borders the San Francisco Bay on its northern, western, and southern sides. Its longest commercial runway, 11/29, is located on the airport's western end and was constructed on bay fill in the 1960s. The airport property is organized into two distinct facility areas: South Field and North Field. South Field, the airport area south of Ron Cowan Parkway, is used by commercial airline service and air cargo. North Field, north of Ron Cowan Parkway, is used for general aviation. Land along the northwestern end of the airport consists of the Chuck Corica Golf Complex and an array of low-density residential development, while land along the eastern end of the airport contains industrial land uses and a golf course, the Metropolitan Golf Links. Some natural areas exist around the airport, such as the tidal flats along the western edge of Runway 11/29 and the mud flats adjoining the southern end of the airport adjacent to the terminal buildings.

Runways constitute the largest aviation land use at OAK at approximately 1,078 acres (Port of Oakland 2006). South Field contains 208 acres of passenger facilities, including Terminals 1 and 2. Runway 11/29 is the South Field's primary runway that provides service to large commercial aircraft. Additionally, South Field has 104 acres of air cargo facilities, the largest of which is the FedEx Metroplex, the largest west coast hub operation for the shipping company. On the other side of the airport, North Field has a variety of land uses, the largest of which is general aviation (approximately 85 acres), including aircraft hangars, ramps, and two fixed base operators, KaiserAir and Business Jet Center. North Field also accommodates some air cargo facilities (approximately 30 acres), including Ameriflight, a small package carrier. North Field's three runways (Runway 9R-27L, Runway 9L-27R, and Runway 15-33) provide service to smaller aircraft, including general aviation and air cargo.

Exposure

Exposure is the extent to which an asset, such as a facility at OAK, experiences a specific climate impact such as storm event flooding, tidal inundation, or elevated groundwater. The exposure of selected facilities at OAK to two sea level rise projections and three Bay water levels was evaluated. The two sea level rise projections, 16 inches (40 cm), and 55 inches (140 cm), correlate approximately to mid- and end-of-century. These two sea level rise projections were coupled with three Bay water levels: the new daily high tide, measured as mean higher high water (MHHW), the new 100-year extreme water level, also known as the 100-year stillwater elevation, and the 100-year extreme water level coupled with wind waves, hereafter "storm event with wind waves," or "wind waves." These water levels were selected because they represent a reasonable range of potential Bay conditions that will affect flooding and inundation along the shoreline. For each exposed facility, the average depth of inundation from the daily high tide and storm events was calculated. Whether a facility is exposed to wind waves was evaluated as a simple binary – yes or no. For more information about sea level rise projections and Bay water levels evaluated see Chapters 1 and 2.

The extent of the facility footprint exposed to each sea level rise projection and Bay water level was determined for each airport asset evaluated. Facility footprints were identified using aerial imagery in combination with the Alameda County Assessor parcel information, and are therefore an approximation rather than an exact facility boundary (see Appendix C).

With 16 inches of sea level rise, the General Aviation facilities and the North Field runways are likely to be inundated by the new daily high tide to depths of approximately 3 to 4 feet (Table 1). During a storm event, potential inundation depth increase by approximately 2 feet, and new facilities are exposed, including the commercial runway at South Field. The inundation depths at these sites range from less than 1 foot at the Maintenance Hangar to nearly 7 feet at the commercial runways and taxiways.

With 55 inches of sea level rise, the entirety of the airport would be exposed to the daily high tide (Table 1). Inundation depths range from a low of approximately 1 foot at the Maintenance Hangar facility near Airport Drive to a high of over 7 feet at the commercial airfield runways and taxiways. During a storm events, inundation levels become significantly higher. Some of the airport's facilities are located at a lower elevation than adjacent areas currently within the daily tidal range, and are therefore more vulnerable to wind waves; these include assets such as the jet fuel storage tanks, commercial runways, and air cargo facilities. Currently, these assets are not exposed to flooding due to protective structures such as tide gates and levees, but when subjected to storm event flooding, it is possible that wind waves will overtop these protective structures, causing even greater amounts of inundation. In storm events, every facility at the airport may be flooded up to several feet. More specifically, the runways and taxiways at the general aviation airfield at North Field and the commercial and cargo airfield at South Field may be inundated by as much as 10 feet.

Table 1. Exposure of select assets at Oakland International Airport to the daily high tide and storm events with 16 and 55 inches of sea level rise. All assets exposed to storm event flooding are also within the wind wave zone and could experience deeper inundation than estimated because Bay water levels increase when there are wind waves.

	16" SLR		55" SLR	
	Daily High Tide	Storm Event Flooding and wind waves	Daily High Tide	Storm Event Flooding and wind waves
Airport Asset Name	**Average depth (ft)**	**Average depth (ft)**	**Average depth (ft)**	**Average depth (ft)**
Jet Fuel Storage		5	5	8
General Aviation	3	5	6	8
North Airfield Runways & Taxiways	4	6	7	9
South Airfield Runway & Taxiways		7	7	10
Air Cargo		3	4	6
Maintenance Hangar			1	4
Passenger Terminals		3	4	6

OAK is dependent not only on its own facilities, but also on the connecting transportation infrastructure that enables workers and passengers to access the airport and allows goods to be transported to and from the airport air cargo facilities. This means that the airport is sensitive not only to climate impacts within its own property, but also to impacts on surrounding areas, such as those that provide access to the airport. Vulnerability of ground transportation assets that provide access to airport will affect the airport's sea level rise vulnerability and risk (see Chapter 11 for an assessment of Ground Transportation assets in the ART project area).

OAK depends on three major access roads for the transit of goods and people to and from Interstate 880 (the nearest major Interstate highway) and major East Bay public transit hubs: Hegenberger Road, 98th Avenue, and CA-61. Table 2 summarizes the exposure of the access routes to the Oakland International Airport.

With 16 inches of sea level rise, all sections of Hegenberger Road south of Interstate 880 could experience up to 2 feet of inundation during storm events. Airport Road, the only link between all three major access roads and the airport's terminal facilities will be impassable because it is an underpass, and therefore could be inundated by up to 26 feet.

With 55 inches of sea level rise, most of the Airport's major services that lie along Hegenberger Road, 98th Avenue, and Doolittle Drive, such as hotels, gas stations, and restaurants, will be inundated by the daily high tide. Hegenberger Road, where most of OAK's hotels are located, will be inundated by up to 3 feet from airport property to Interstate 880 and the Oakland Coliseum station complex. The other routes, 98th Avenue and CA-61/Doolittle Road, will be exposed to flooding during storm events. CA-61 on Oakland's North Field is crucial to the airport's services as it is home to most of the airport's major "on-property" rental car facilities, including a 15,000-square-foot rental car center.

Ron Cowan Parkway, an alternate route to the airport from Alameda and Bay Farm Island, could be vulnerable to inundation under all sea level rise scenarios. With 16 inches of sea level rise, Ron Cowan Parkway may face 15 feet of inundation at high tide.

Table 2. Exposure of selected road assets at Oakland International Airport to the daily high tide and storm event flooding with 16 inches and 55 inches of sea level rise. All assets exposed to storm event flooding are also within the wind wave zone and could experience deeper inundation than estimated because Bay water levels increase when there are wind waves.

	16" SLR			55" SLR	
	Daily High Tide	Storm Event Flooding		Daily High Tide	Storm Event Flooding and wind waves
Selected road asset name	**Average depth (ft)**	**Average depth (ft)**	**Exposed to wind waves only**	**Average depth (ft)**	**Average depth (ft)**
Hegenberger Rd. (San Leandro St. to Coliseum Way)			Yes	3	5
Hegenberger Rd. (SB I-880 Off-Ramp to Coliseum Way)		2		3	5
Hegenberger Rd. (Edgewater Dr. to Pardee Dr. / Airport Access Rd.)		2		3	5
Hegenberger Rd. (Pardee Dr. / Airport Access Rd. to Doolittle Dr.)		2		3	5
Airport Dr. (Entire Facility)		26		27	29
Ron Cowan Parkway (Entire Facility)	15	19		19	22

Sensitivity and Adaptive Capacity

The sensitivity and adaptive capacity of the Airport was assessed for three potential climate impacts that could occur due to sea level rise and storm events. The three climate impacts considered are:

- More frequent floods or floods that last longer due to storm events
- Permanent or frequent inundation by the daily high tide
- Elevated groundwater levels and saltwater intrusion

Sensitivity is the degree to which an asset or entire system would be physically or functionally impaired if exposed to a climate impact. Adaptive capacity is the ability for an asset or system to accommodate or adjust to a climate impact and maintain or quickly resume its primary function. The sensitivity and adaptive capacity of the Airport was evaluated, considering not just physical and functional sensitivity of airport facilities, but also the sensitivity of the access roads transportation and key support services and facilities the airport relies upon.

OAK requires un-flooded runways and facilities in order to move people and goods. The combination of the airport's low-lying elevation and its physical sensitivity to flooding make the airport's function vulnerable to multiple sea level rise scenarios. The airport is particularly sensitive to storm events when water may overtop protective levees. As discussed in the exposure analysis, every facility at the airport could be inundated up to several feet when subjected to storm event flooding with 55 inches of sea level rise.

In addition to flooding, the airport sits on bay fill. This makes OAK more physically vulnerable to inundation or liquefaction than areas farther inland. Most of the original airfield was constructed through reclamation in the late 1950s and consists of hydraulically placed sand fill. The perimeter dike, with a width of 18 to 28 feet and situated 9 to 17.5 feet above the Bay, is underlain by silty clay and young Bay mud, which has a high liquefaction potential. During a seismic event OAK is vulnerable to liquefaction which could magnify the impacts of flooding and other natural events on its physical structures, especially runways that rely on flat, even terrain for departures. The risk of liquefaction is particularly high for the levee that protects the airport. To address this issue, the Port's Environmental Programs and Planning Division has focused on industry-leading project designs that enable runoff from roadways, parking lots and buildings to divert to grassy swales, detention basins, and landscape areas to allow for increased infiltration and treatment prior to discharging water off-site.

Consequences

Consequences are the magnitude of the effects on the economy, society, environment, and governance if an impact occurs. Factors that inform the magnitude of the potential consequences include the severity of the impact on O&M or capital improvement costs, the size and demographics of the population, and the type of natural resources affected. The potential consequences of daily tidal inundation, storm event flooding, or elevated groundwater on Oakland International Airport are considered as a whole, which expands the coverage of this report to include communities served by OAK.

<u>Economy</u>

OAK is near a number of highways, roads, and public transit routes, and provides a convenient way for air travelers throughout the ART project area and the greater Bay Area to fly across the state, across the nation, or around the world. The airport's low-lying runways are at risk of inundation and it is likely that in a storm event with 16 inches of sea level rise, OAK will have to reduce or redirect aviation activity to other Bay Area airports such as San Francisco

International Airport and San Jose Mineta International Airport. Any form of inundation affecting OAK's ability to handle flights could have a significant impact on the entire regional and national network of air traffic.

OAK hosts flights departing from various points throughout California, the United States, and Mexico, and is a focus city for Southwest Airlines and Allegiant Air. In 2010, OAK carried 9,857,845 passengers, making it the 33rd busiest airport in the U.S. in terms of total passengers (Airports Council International 2009), and 34th busiest in the U.S. in terms of total aircraft movements, at 219,652 landings and takeoffs. OAK's air cargo traffic was also among the highest in the U.S. in 2010, ranking 10th with 510,947 metric tons handled. The airport is the North American West Coast hub for FedEx, the largest air cargo operator at OAK which sorts and distributes freight and overnight packages from around the world. In 2010, FedEx averaged 15 flights a day, handling 907 million pounds of cargo (Port of Oakland 2011).

Any inundation-related impacts to OAK's runways could mean that all of these flights and networks will be affected in the form of significant delays or re-routings, meaning lost time or lost money for both passengers and air carriers. Additionally, the airport would have to pay for costly repairs to any dikes, pavements, and structures that flood. OAK has paid for such incidents in the past. During strong winter storms in 1983, a historically active winter rain season, parts of OAK's main dike were overtopped. The Port of Oakland made emergency repairs to the damage by filling the Bay side of the overtopped sections of the levee with up to 15 feet of concrete rubble, and filling the landside dike with gravel fills. The cost of these initial repairs totaled $429,743, while a complete reconstruction of the dike was later carried out at a cost of $975,020 (Port of Oakland 1984). With the exception of the overtopping in 1983, the perimeter dike has performed well in protecting the airport's facilities from flooding and storm events.

OAK's location on top of bay fill makes it particularly susceptible to liquefaction during a seismic event. The 1989 Loma Prieta earthquake affected airport operations even though the airport was over 40 miles from the epicenter. The airport's main 10,000-foot runway (South Field's Runway 11-29), built on hydraulic fill over Bay mud, was severely damaged by liquefaction; 3,000 feet of the runway sustained cracks, some of which were up to one foot wide and one foot deep (USGS 1998). Spreading of the adjacent unpaved ground resulted in cracks up to 3 feet wide. Large sand boils, some as wide as 40 feet, appeared on the runway and adjacent taxiway. As a result, OAK was immediately shut down to evaluate runway damage.

North Field's 6,212-foot general aviation runway (Runway 9R-27L) was used to accommodate diverted air traffic for several hours before the main runway was reopened with a usable length of only 7,000 feet. This shorter runway length affected cargo loads during takeoff. Over the thirty days following the earthquake, 1,500 feet of the 3,000-foot damaged section of the runway was repaired using an emergency repair order for resurfacing and local crews. An adjacent taxiway was also damaged by liquefaction. Repairs of this taxiway segment and the final 1,500 feet of the main runway were completed six months later, with repair costs totaling approximately $6.8 million. This total included $3.5 million for runway repairs, $2.2 million for taxiway repairs, and $1.1 million for repair of other (non-liquefaction related) damage, including a below-grade tramway used to transport baggage under terminal buildings, which was filled with sand and water up to six and a half feet deep. FAA funded approximately $5.5 million of the repairs, with the remainder funded by OAK. Sea level rise and coincident groundwater rise will increase the risk of liquefaction at OAK and surrounding areas.

Society

As a major link in northern California's transportation network, OAK supports thousands of jobs directly through its operations and indirectly via the industries that require a functioning airport. Any event resulting in major inundation would temporarily interrupt the road and public transport links that many people rely on to get to and from the airport, especially those that are dependent on public transportation. AC Transit, the third-largest bus system in California, operates bus service to and from OAK and nearby Alameda County, with connections to surrounding Contra Costa County. Many airport employees rely on these services to transport them from their homes to the terminal areas.

Line 73 of AC Transit is a local service operating between OAK and the Eastmont Transit Center in Oakland. Line 73 passes through BART Coliseum/Oakland Airport Station, but continues east and provides access for employees in Oakland who do not have convenient access to BART. This route traverses Airport Drive, which could be inundated in storm events with 16 inches of sea level rise.

Line 21 of AC Transit is a local service operating between the Dimond District in Oakland and OAK. Between these two points, the bus travels through the Fruitvale BART Station, Alameda Island, and Bay Farm Island with selected trips to the Alameda Harbor Bay Ferry Terminal (southernmost ferry service to San Francisco), allowing public transit access for employees who live west and north of OAK. This route traverses Ron Cowan Parkway, which is highly susceptible to inundation and liquefaction; therefore, interruption of service is highly probable, even during the daily high tide with 16 inches of sea level rise.

Public transport and road closures to OAK will cause problems for large numbers of employees who work on or near the airport's premises. In the Bay Area in 2010, aviation activity from OAK generated 7,680 direct, 5,578 induced, and 1,408 indirect jobs, for a total of 14,466 jobs (Table 3).

The direct jobs supported by the airport include a range of public and private sector employment, from air traffic controllers working for the FAA to bus drivers operating private airport shuttles. These jobs generated $4.2 billion in business revenue and $1.9 billion in personal income. OAK also generated $197 million in state and local taxes and provided a direct payment of $3.2 million to the City of Oakland. A reduction in convenient access to OAK for airport and airport-related employees could translate into significant economic losses to the City of Oakland, the Port of Oakland, and the entire State of California.

Table 3. Direct and indirect jobs dependent on aviation activity at OAK (Source: Port of Oakland)

Impact Category	Impact Sub-Category	Number of Direct Jobs by Category
Surface Transportation	Rail	174
	Truck	3,708
	Subtotal	*3,882*
Maritime Services Sector	Terminal Employees	210
	ILWU	1,701
	Towing	78
	Pilots	47
	Steamship Lines / Agents	168
	Maritime Services	559
	Freight Forwarders	1,616
	Warehouse / Distribution Centers	1,955
	Government	416
	Marine Construction / Ship Repair	145
	Subtotal	*6,894*
Dependent Shippers/Consignees		88
Port of Oakland		63
	Grand Total	**10,927**

For air travelers, the regional access roads of OAK serve an integral role in shuttling passengers in and out of the terminal facilities. Many of these roads will be inundated with 16 inches of sea level rise. Ron Cowan Parkway, a secondary travel route for OAK passengers traveling from Alameda communities, has high seismic liquefaction potential and will be inundated up to 15 feet under the new daily high tide with 16 inches of sea level rise. Airport Drive, the primary access road to OAK, will be inundated up to 26 feet during storm events with 16 inches of sea level rise. Rental car and hotel facilities are located along these major access roads, meaning that even if the airport is not exposed, it could face major difficulties connecting arriving and departing passengers to these services. This may translate into lost revenue for OAK's service industry as well as economic losses for the 24,428 employees in the hospitality industry along these corridors.

BART's Coliseum/Oakland Airport Station is the primary gateway for regional rail commuters and air travelers to OAK from other parts of the East Bay and the greater Bay Area. In FY2010, it served 20,785 Amtrak passengers yearly[1] and 6,191 BART passengers daily[2]. The station opened as part of BART's initial service in 1972, and today, for an additional fee, passengers connect to the airport through a private shuttle bus service known as AirBART. In October 2010, construction began on a new $500 million Automated Guideway Transit (AGT) system to OAK, known as the Oakland Airport Connector and slated for completion in mid-2014[3]. The future Airport Connector will be on an elevated rail line and therefore may not be directly affected by inundation. However, if flooding occurs before the rail line is completed, AirBART service to and from OAK's terminals could be suspended; eliminating another means of access to the airport.

[1] http://www.amtrak.com/pdf/factsheets/CALIFORNIA10.pdf
[2] http://www.bart.gov/docs/WeekdayExits.pdf
[3] http://www.bart.gov/about/projects/oac/

Environment

OAK's primary commercial runway, 9R-27L, is situated adjacent to a protective dike that is highly susceptible to structural failure due to high liquefaction vulnerability. During the Loma Prieta Earthquake of 1989, Runway 9R-27L experienced a dike failure and was temporarily closed to all arrivals and departures while emergency repairs were being made. During this time, commercial aircraft were temporarily re-routed to the North Field runways. While these runways are capable of serving commercial aircraft in times of emergencies, local communities and businesses experience a significant increase in noise-related impacts.

Commercial aircraft are much louder than general aviation aircraft, contributing to higher CNEL (Community Noise Equivalent Level) measurements. If commercial aircraft were to be re-routed on the North Field runways, many residents in the City of Alameda, City of Oakland and City of San Leandro could be affected by a significant increase in overall decibel levels, especially if current take-off and landing patterns were maintained. The closure of Runway 9R-27L, therefore, would not only bring significant economic impacts to the Bay Area, but could also cause health-related impacts to local residents and businesses.

Finally, while OAK has made a leading effort to improve stormwater management and treatment over the past 15 years[4], it is still possible that water from the San Francisco Bay could flow through sewage facilities and contaminate other structures on the airport property should Bay water overtop the protective dike structure. According to the Port of Oakland's Aviation Planning and Development, contamination from sewage conveyance and treatment systems is possible in the event of major inundation, which could in turn contaminate groundwater beneath the airport.

Governance

The airport's physical and regulatory structure reduces its capacity to adapt its operations, including takeoff and landing patterns, in the event of significant disruption. While the airport has maintenance personnel, heavy equipment, stockpiles of repair materials to repair an emergency dike breach, and a system of pumphouses to remove floodwaters, it would not be able to quickly or easily restore significant flood-related damage to pavements (runways, taxiways, and aprons) or critical utilities (e.g., airfield lighting and navigational aids). Because OAK's sole runway for commercial flights is also the airport's most vulnerable to flooding (Runway 11/29), it is highly possible that major operational adjustments will be needed in the event of inundation. However, these major operational adjustments will not be easy to swiftly implement due to a large number of overlapping local and federal airspace regulations.

For example, if Runway 11/29 were inundated, the only alternative stretches of pavement where commercial jets could possibly land are the rest of the airport's secondary runways on the North Field (Runways 27L/9R, 27R/9L, 19/33). These runways are shorter and narrower than Runway 11/29 and are restricted by local regulations. As a result of the Airport Development Program Settlement Agreement among the Port of Oakland, the City of San Leandro, the City of Alameda, and others, the Port agreed to prohibit the use of North Field runways by regularly scheduled large commercial aircraft, essentially making the use of these airways exclusive to general aviation and cargo flights. This agreement was made to reduce the amount of noise generated by commercial takeoffs and landings to the surrounding communities, but it also reduces the airport's adaptive capacity to relocate commercial flights on these alternate runways.

[4] http://aci-na.org/static/entransit/enviro_brochure.pdf

Moreover, federal regulations limit the airport's adaptive capacity to relocate flights on secondary runways 27L/9R, 27R/9L, and 19/33. At major airports throughout the country, FAA regulations and airport policies dictate what types of plane can land on runways, and also how they land. The FAA imposes a 24-hour noise abatement policy on OAK which prohibits turbojet and turbofan powered aircraft, turboprops over 17,000 pounds, four-engine reciprocating powered aircraft, and surplus military aircraft over 12,500 pounds from departing on runways 27L and 27R or landing on runways 9R and 9L[5].

In the event of an emergency, or whenever Runway 11/29 is closed due to maintenance, safety, high wind, or weather, the above-mentioned noise prohibitions could be waived. Local communities and businesses, however, would experience noticeable increases in noise-related impacts, because the landing patterns of louder commercial jets would shift toward residential areas instead of over the waters of the San Francisco Bay. $4.5 million has been budgeted by the Port of Oakland for environmental and community benefits, which has been concentrated on mitigating noise generated by commercial takeoffs and landings on Runway 11/29.

Additionally, facility operations and maintenance budgets are very complex, making it difficult for the airport to quickly arrange funding for immediate repairs. The Port of Oakland's capital planning process begins with the development of a Five-Year Capital Needs Assessment (CNA). This document is updated annually and identifies non-capacity expanding needs in order to operate and maintain existing infrastructure that is in a state of good repair. These projects are not financially committed; rather, they are a list of projects for which the Port should explore funding in order to ensure competitiveness with other maritime, aviation, and commercial real estate operations.

Once included in the CNA, the Board of Port Commissioners approves projects based on available funding and need. In its five year 2012-2016 Capital Needs Assessment, the airport has identified $423 million for aviation projects divided into six categories: Airfield Safety and Security; Airfield Pavement; Terminal Renovation and Retrofit; Parking, Roadways, and Rental Car; Environmental and/or Community Benefit; and Utility Infrastructure Maintenance. Over half of this total, or $219 million, is to come from Passenger Facility Charges (PFCs), ticket fees collected by the airlines from departing passengers to fund FAA-approved projects that enhance safety, security, capacity, noise impacts, or air carrier competition at airports throughout the country. The current maximum PFC charge is $4.50 per passenger, although there is discussion in Congress to increase this level to $7.00.

Another $108 million, or roughly one quarter of the total capital budget, is expected to come from government grants. These grants are generally in the form of FAA Airport Improvement Program funds (AIP). The AIP funds are both entitlement and discretionary and can pay for up to 80% of eligible projects, with the remaining 20% locally matched from airport-generated sources. The remaining funding for the CNA, roughly $96 million, is expected to come from aviation-generated operating revenue and debt.

Among the major projects included in the CNA are:

- $34 million budgeted for airfield pavement rehabilitation. Projects include: design and construction of two Taxiways ("Whiskey" and "Uniform") in South Field.
- $100 million budgeted for upgrades to Runway Safety Areas (RSAs) that do not meet FAA's 1,000-foot length standards.

[5] http://www.boeing.com/commercial/noise/metro_oakland.html

- $174 million budgeted for Terminal One Renovation and Retrofit Project, including seismic retrofits, ADA compliance, HVAC improvements, fire alarms/suppression, flooring and lighting, and renovation/replacement of central utility plant.

Although these projects will help improve the airport's long-term infrastructure capacity, a backlog of significant but currently unfunded projects remains. These projects include:

- $126 million in additional Terminal One improvements
- $9 million in stormwater infrastructure upgrades
- $3 million in North Field facilities improvements

These important projects will only be completed when unexpected funding sources, such as government grants or better-than-expected revenues from airport operations, become available. As such, it is difficult for the airport to plan for and execute these needed upgrades. For example, the airport's new 236-foot tall air traffic control tower and 13,000-square foot administrative base building is currently under construction and is expected to open in 2013. This long-awaited $31 million project, paid for by Federal American Recovery and Reinvestment Act funding, will replace the two existing North and South Field towers with one state-of-the-art facility. The money for this project, however, is from a one-time source. Inadequate and/or uncertain funding sources for both basic upkeep and necessary repair of critical infrastructure reduces the airport's capacity to both plan for future impacts and restore potential disruptions from climate change. Restrictions on OAK's operational and financial actions reduce the airport's adaptive capacity with regard to sea level rise.

Without proper flood protection in place, OAK will be faced with additional regulatory burdens. For example, OAK's existing perimeter dike structure does not meet FEMA 100-year flood protection standards, which means that it is no longer given accreditation under FEMA's flood programs. The lack of accreditation means that OAK must also obtain federal flood insurance on top of the private flood insurance the Port of Oakland already carries. If the airport fails to upgrade the dike to FEMA standards, not only would it become largely ineligible for federal disaster assistance in the event of a levee failure, but it would also require the Port to develop a Flood Plain Management Plan that mandates significant restrictions on the construction of new buildings or significant improvement of existing buildings. The requirements, for example, mandate that new or existing structures should be designed so that the lowest floor is elevated above the projected base flood level, or be designed so that structures below the base flood level are watertight.

Key Findings

The majority of the airport assets, including both North Field (general aviation) and South Field (commercial and cargo aviation) runways, are exposed to 16 inches of sea level rise with a storm event. With 55 inches of sea level rise and a storm event, all airport assets are exposed to some amount of inundation, up to great depths in some locations. The airport's physical assets and it functional role in the region are highly sensitive to inundation and have little to no adaptive capacity.

Based on the exposure mapping, the airport assets that are exposed first are all of the roadways that serve the airport (Ron Cowan Parkway, Hegenberger Road, Airport Road, Doolittle Drive), North Field, and the airport services that are located off of Ron Cowan Parkway. This exposure begins at the daily high tide with 16 inches of sea level rise, and increases significantly with a storm event. The commercial runway which provides both cargo and passenger service is also exposed to these impacts.

The functional role that Oakland International Airport plays in the region, state, and nation as a commercial, cargo and general aviation airport cannot be met by other airports or sites in the region. Were Oakland International Airport to lose either North or South Field (or both), there is not enough capacity to meet the demand for these services at other airports or other sites within the region. Moving passenger, cargo or general aviation services to San Francisco International Airport, Norman Mineta International Airport in San Jose, and the surrounding general aviation airports would result in significant delays at those airports. The airport with the most available capacity is Norman Mineta International Airport. However, much of the commercial passenger demand would likely move to SFO, which does not have the capacity to absorb such an increase. The functional role served by OAK as a passenger, cargo, and general aviation airport does not have redundancy in the region and would result in effects on local, regional, state and national air transportation.

The airport is the site of significant numbers of jobs and provides a large economic benefit to both the subregion and the region. The airport's location in the City of Oakland results in a large number of jobs at surrounding facilities created to serve the airport, as well as those jobs that are needed to support the movement of cargo to and from the airport and the businesses and services that are located in the surrounding areas because of the close proximity to an international airport with regular, dependable service.

There are a number of potential environmental consequences from the loss of service at Oakland International Airport. If the airport operations were adapted to move passenger and cargo service from the commercial runway at South Field to the general aviation runway at North Field, it would result in significant noise increases in neighboring residential areas. The movement of general aviation service from North Field to the commercial and cargo runway at South Field would result in significant delays to South Field and have effects on both commercial and cargo transport. The movement of cargo service from Oakland to either San Jose or Sacramento would result in increased distances needed to move cargo by truck, resulting in increased air quality effects and fuel use.

The role of the Federal Aviation Administration, the airlines, and local, state, and federal regulations in the way that the Port of Oakland can operate, finance and maintain the facilities at Oakland International Airport constrain its adaptive capacity to respond quickly to the effects of sea level rise and storm events. Most airport projects take a number of years to plan, finance and implement.

Due to the airport's sensitivity to the impacts of sea level rise and its difficulty in adapting to inundation by altering operations or maintenance, it is highly likely that the adaptation response to the airport's vulnerability will primarily be to reduce exposure to sea level rise and storm event flooding. The way in which the adaptation response is developed will need to be sensitive to the significant number of other subregional assets both at the site of the airport and adjacent to it. These assets include Bay Farm Island, Martin Luther King Jr. Regional Shoreline and Arrowhead Marsh, the BART connection to the airport, the roadway access to the airport, and the infrastructure (pipelines, storm water, waste water, communications and energy, etc.) serving the airport and its surroundings. The adaptation response should be developed with these partners.

References

Airports Council International. 2010. ACI World Report. http://www.aci.aero/aci/aci/file/World%20Report/2010/WorldReportFebruary2010.pdf.

Port of Oakland. 1984. Jan. 17, 1984 Port Commissioners' Meeting, City of Oakland.

Port of Oakland. 2006. Oakland International Master Plan. http://www.oaklandairport.com/masterplan_oak/support_documents.shtml.

Port of Oakland. 2011. Strategic Plan, Fiscal Years 2011-2015. http://www.portofoakland.com/pdf/2011_pbs_02.pdf.

USGS. 1998. The Loma Prieta, California, Earthquake of October 17, 1989—Liquefaction. Soil Liquefaction in the East Bay During the Earthquake. http://walrus.wr.usgs.gov/geotech/soil.

Chapter 10. Seaport

The Port of Oakland (Port) is an autonomous department of the City of Oakland. The Port manages property along 20 miles of the eastern shore of San Francisco Bay and is divided into three operating units: Maritime, which owns and operates the Seaport; Aviation, which owns and operates Oakland International Airport; Commercial Real Estate, which owns property along the shoreline. The Port was officially established in 1927 under the direct control of the Board of Port Commissioners. As an independent department, the Port funds its own operations and receives no tax revenues from the city. The Port is located to the west of Interstate 880 and south of the San Francisco-Oakland Bay Bridge (Interstate 80). The residential and industrial community of West Oakland is located immediately to the east, and downtown Oakland, the Bay Area's second largest central business district, is located to the northeast.

The Seaport is landlord-based, meaning it owns and builds most of the port infrastructure, but private shipping companies are responsible for operations at the terminals they lease. The Port is made up of a number of facilities, including

- Shipping berths, container storage areas, and intermodal rail facilities, which constitute approximately 1,200 acres
- Four major terminal areas, which together total 775 acres:
    - Outer Harbor Terminal Area
    - 7th Street Terminal Area
    - Middle Harbor Terminal Area
    - Inner Harbor Area
- 20 deep water berths (depths of 50 feet)
- 36 container gantry cranes (30 are post-Panamax types)
- Two intermodal rail yards:
    - Oakland International Gateway (OIG), operated by Burlington Northern Santa Fe on Port-owned land
    - Railport, owned and operated by Union Pacific Railroad on adjacent private property
- Oakland Army Base – while not officially part of the Port, some ancillary Port services take place on the former Oakland Army Base, also referred to as the "backland"

Exposure

Exposure is the extent to which an asset experiences a specific climate impact such as storm event flooding, tidal inundation, or elevated groundwater. The exposure of the Seaport to two sea level rise projections and three Bay water levels was evaluated using two different approaches. The two sea level rise projections, 16 inches (40 cm) and 55 inches (140 cm), correlate approximately to mid- and end-of-century. These two sea level rise projections were coupled with three Bay water levels: the new daily high tide, measured as mean higher high water (MHHW), the new 100-year extreme water level, also known as the 100-year stillwater elevation, and the 100-year extreme water level coupled with wind waves, hereafter :"storm event with wind waves," or "wind waves." These water levels were selected because they represent a reasonable range of potential Bay conditions that will affect flooding and inundation along the shoreline. For more information about sea level rise projections and Bay water levels evaluated see Chapters 1 and 2.

For each of the water levels, the exposure of selected facilities within and associated with the Port of Oakland was evaluated. As shown in Table 1, the Port is not exposed to the daily high tide or storm event flooding with 16 inches of sea level rise, although portions of two terminal areas, the Union Pacific Railport, and some of the Oakland Army Base are exposed to wind waves. With 55 inches of sea level rise, parts of the Railport, Oakland Army Base, and portions of rail track are exposed to the daily high tide; these areas and parts of the Outer Harbor Terminal Area are exposed to storm event flooding, and all of the selected Port assets except for the 7th Street Terminal Area and Oakland International Gateway are exposed to wind waves.

Table 1. Selected Port assets exposed to wind waves with 16 inches of sea level rise, and daily high tide and storm events with 55 inches of sea level rise. No areas are exposed to the daily high tide or storm event flooding with 16 inches of sea level rise.

	16" SLR	55" SLR		
	Storm Event	Daily High Tide	Storm Event	
Port Asset / Area	**Areas exposed to wind waves only**	**Areas exposed**	**Areas exposed**	**Areas exposed to wind waves only**
Outer Harbor Terminal Area	Parts of Terminal, incl. Berths 20-37		Parts of Terminal, incl. Berths 20-37	Parts of Terminal, incl. Berths 20-37
7th Street Terminal Area				
Middle Harbor Terminal Area	Parts of Terminal, incl. Berths 60-68			Parts of Terminal, incl. Berths 55-59
Inner Harbor Area			Parts of Terminal, incl. Berths 60-68	Parts of Terminal, incl. Berths 60-68
Oakland International Gateway				
Union Pacific Railport	Parts of Railport	Parts of Railport	Parts of Railport	Parts of Railport
Oakland Army Base	Parts of Port areas on Base	Parts of Port areas on Base	Many Port areas on Base	Many Port areas on Base
Rail Tracks serving Port		Tracks south of Port near Lake Merritt	Tracks north and south of Port	Tracks north and south of Port

Sensitivity and Adaptive Capacity

The sensitivity and adaptive capacity of the Port was assessed for three potential climate impacts that could occur due to sea level rise and storm events. The three climate impacts considered are:

- More frequent floods or floods that last longer due to storm events
- Permanent or frequent inundation by the daily high tide
- Elevated groundwater levels and saltwater intrusion

Sensitivity is the degree to which an asset or entire system (e.g., particular terminals or related services such as rail and roads) would be physically or functionally impaired if exposed to a climate impact. Adaptive capacity is the ability for an asset or system to accommodate or adjust to a climate impact and maintain or quickly resume its primary function. The sensitivity and adaptive capacity of the Port was evaluated, considering not just physical sensitivity, but also functional sensitivity and the sensitivity of the regional goods movement network.

Rising groundwater could increase the potential for liquefaction-induced damage. The seaport is located on sandy Bay fills which are subject to liquefaction. Damage to facilities at the Port of Oakland in the 1989 Loma Prieta earthquake was due primarily to liquefaction of the hydraulic fill (ABAG 2001). All of the terminals were affected, with the most extensive damage to the Seventh Street Terminal (Berths 35-38). Ground acceleration at the Port caused widespread liquefaction and sand boils in several terminals, resulting in up to one foot of settlement and distress to backland pavement, utilities, and small buildings. The damage to wharf structures at the Seventh Street Terminal was severe enough to close the terminal for several months and reduce its operations for over a year until emergency repairs were completed.

Redundancy and excess capacity at the seaport can help reduce potential impacts of sea level rise if terminal areas and/or berths are temporarily impaired. At its present size and with its existing rail infrastructure, the Port is projected to have adequate capacity through 2021 (Tioga Group 2009). Infrastructure improvements on rail and road connections would enable the Port to meet forecast demand through 2030. Thus, the Port of Oakland is not faced with immediate capacity constraints based on projected cargo demand and could potentially absorb additional goods movement at its other terminals should one be rendered inoperable. This sort of adaptive capacity was observed when the Loma Prieta Earthquake forced the closure of the 7th Street Terminal for over a year. The ability of other terminals to compensate for the temporary closure of other parts of the Port is only possible when impacts are confined to small areas.

Some Port assets are not directly exposed to tidal inundation or storm event flooding with sea level rise, but are sensitive to potential impacts on the terminal areas' substructure support systems. Terminal decks are supported by concrete pilings embedded in a rock dike embankment that slopes down to the terminal water depth, which ranges from 42 to 50 feet below mean lower low water. The potential for these structures to be exposed to more climate impacts could compromise their integrity, leading to increased damage and maintenance costs. An example of indirect climate impacts comes from the Port of Los Angeles, which predicts that an increase in sea levels would affect its storm drain system (Vera 2009), which would act as a conduit for sea water, flooding the terminals and surrounding streets.

Regular maintenance and the ability to quickly repair damaged facilities could contribute to the adaptive capacity of terminal areas and substructure support systems, but operations and maintenance costs are very high and the financial mechanisms to improve seaport infrastructure are complicated. In its five year 2012-2016 Capital Needs Assessment, the seaport budgets $146 million for maritime projects (Port of Oakland 2011). About two-thirds of this total is to come from Port-generated cash and must be used to pay for operations, debt service, and other obligations first, with any remainder to fund capital projects. The remaining one-third of the budget is expected to come from grants from government agencies including the Federal Maritime Administration, California Air Resources Board, Bay Area Air Quality Management District, and Metropolitan Transportation Commission. The high cost of budgeted infrastructure improvements does not include protecting against future sea level rise and flooding impacts. Such protection would increase budgets substantially – for example, the Port of Los Angeles estimates that hardening its terminals and berths to withstand projected mid- to end-of-century sea level rise would cost 25% more than current upgrade costs (Rand 2011).

The seaport is dependent on berths and terminals to dock shipping vessels and unload their cargo and also on the adjacent rail yards and freeways that carry those goods to other parts of the region, state, and country. Thirty percent of goods moving into and out of the Port are transported by rail (Port of Oakland 2008). As noted in Table 1, portions of track and other rail assets that serve the Port are exposed to wind waves with 16 inches of sea level rise, and all Bay water levels with 55 inches of sea level rise.

The rail system that serves the Port of Oakland cannot function when flooded. Inspection and work pits at railroad maintenance facilities have pumping equipment meant to keep them dry in the event of storm event flooding or groundwater intrusion. However, this pumping equipment has limited capacity so its effectiveness would depend on the severity of flooding. While the tracks could return to use quickly after a floodwaters recede, frequent inundation would result in unacceptable delays, essentially forcing the system's infrastructure to either be upgraded or abandoned. To improve the adaptive capacity of the asset to withstand flooding events, the existing right-of-way could be used to build a higher railbed. However, raising the railroad requires related structures to be raised, which would be difficult if not impossible without complete reconstruction.

Seventy percent of the goods moving into and out of the Port are transported by truck to Interstate 880, the primary freeway that connects the Port with points south such as San Jose and Silicon Valley. The segment of I-880 between Oak Street and 23rd Avenueis exposed to inundation from all scenarios except the daily high tide with 16 inches of sea level rise. While trucks could be re-routed in the event of flooding on I-880, this would have impacts on local neighborhoods.

The function of the Port is extremely sensitive to disruption because of the nature of the goods exported. The top commodities exported in 2010 were fresh fruits and nuts and meat products, accounting for over 33% of the total export value (Port of Oakland 2011). These perishable products require quick transport between their source and the market and cannot tolerate delays or the inability to access the Port. Transport of California's agricultural products does have some adaptive capacity. Ninety-nine percent of containerized goods moving through northern California travel through the Port of Oakland, but the Port of Richmond and the Port of San Francisco have the infrastructure in place to handle containerized goods. However, these ports do not currently handle such goods and do not have the capacity of the Port of Oakland. Further, these ports have a maximum water depth of 38' and cannot handle the largest container ships that Oakland's 50' channels can.

Consequences

The potential consequences of sea level rise are considered for the Port and supporting transportation infrastructure. Consequences are the magnitude of the effects on the economy, society, environment, and governance if an impact occurs. Factors that inform the magnitude of the potential consequences include: the type and severity of the impact on O&M or capital improvement costs; the size and demographics of affected communities; the potential impact on employers and employees; and the type of natural resources affected.

Economic

By number of annual TEUs (twenty-foot equivalent units; a standardized size of the containers in which goods are shipped), the Port of Oakland is the 3rd busiest container port on the West Coast of the United States and the 5th busiest in the country. In 2010, 1,973 cargo vessels imported over 2.33 million TEUs through the Port. Primary imports include machinery, electrical equipment, knit apparel, furniture, and beverages, mostly from Asia. The Port's primary exports include fruits, nuts, and meats. In sum, over $39 billion worth of imports and exports flowed through the Port in 2010.

In the Bay Area alone, this cargo activity generated 28,833 direct, induced, and indirect jobs (Martin Associates 2011). Fifty-two percent of the direct jobs created by the Port are within Alameda County, with nearly 20% in the City of Oakland. Eighty-seven percent of the direct jobs are created within northern California. These jobs range from rail and truck operators to unionized longshoremen to bar pilots. The average salary of a Port-related employee is $40,400, better than the average wage of $37,890 for production workers in the Oakland-Fremont-Hayward Metropolitan Area. In total, nearly 444,000 jobs are related, in some way, to the movement of cargo at the Port of Oakland.

In addition to jobs, the revenue brought in by Port activity helps local businesses and communities. In 2010, cargo handled at the Port supported about $2.2 billion of total personal income, $2.1 billion in revenue for businesses providing maritime services for cargo and vessels, and $233 million in state and local tax revenue. Each year, depending on the revenue surplus, the Port makes financial contributions to the City of Oakland. Past large-scale disruptions have had large monetary impacts to the Port. For example, a one-day closure of four berthing areas caused an estimated loss of $4 million (Kuruvila 2011).

In addition to the direct economic losses from a disruption of the Port's operations and facilities, planned projects are expected to increase the economic role the Port of Oakland plays in logistics in the Bay Area, state, and nation. The former Oakland Army Base closed in 1999, with segments transferred to both the City of Oakland and the Port of Oakland. Redevelopment of the site will entail three projects: Marine Terminal Redevelopment on Port-owned property; construction of an Intermodal Rail Terminal also on Port-owned property; and construction of Trade, Logistics, and Industrial Facilities on city-owned property. The Marine Terminal Redevelopment project will entail facility improvements located at Terminals 20-26 in the seaport's Outer Harbor area. The Intermodal Rail Terminal will be located between Maritime Street and Interstate 880 with the goal of increasing rail's share of goods movement to and from the seaport. Finally, the Trade, Logistics, and Industrial Facilities center will develop over 100 acres of land south of the Bay Bridge toll plaza and north of the Port of Oakland's marine terminal facilities into new industrial and cargo processing space for goods movement companies. The City of Oakland hopes to attract manufacturing, research and development, and green technology uses to this area.

The Oakland Army Base redevelopment projects are projected to create roughly 3,000 direct jobs in the near term and 12,000 jobs over the next 20 years; generate $4 million per year for the City of Oakland's general fund; and improve air quality in West Oakland and adjacent communities by reducing truck traffic. However, sea level rise and storm events may affect this site. Much of the former Army Base will be exposed to wind waves with 16 and 55 inches of sea level rise, and to the daily high tide and storm event flooding with 55 inches of sea level rise. The potential for future inundation could prevent development or negatively affect businesses as well as cargo movement if the project is completed as planned.

Society
The Port of Oakland is a key gateway for the export of California's agricultural products. The Port is unique among American ports in that, by volume, it exports more than it imports. More than 60% of all California exports of beverages, spirits, vinegar, coffee and tea, fruits, nuts, citrus, and melon leave the state through Oakland. In 2010, more than $10.1 billion in California-made goods and commodities were shipped through the Port of Oakland, representing over 29% of all exports produced in the state. In the absence of viable alternative export points, disruptions to the Port of Oakland would seriously affect California's agricultural communities.

Because of the Port's location adjacent to residential communities, it has major public health impacts. Goods at the seaport are moved primarily by diesel trucks, which cause air quality problems in the West Oakland community as well as increased traffic congestion on regional freeways. Emissions from Oakland's port operations, rail yards, and freeways cause diesel particulate matter (PM) concentrations that are three times higher in West Oakland than the Bay Area average. Additionally, 40 excess cancers per million residents of West Oakland are attributed to seaport-related truck drayage, and diesel PM is responsible for higher premature deaths and hospital admissions for respiratory and cardiovascular disease, as well as asthma-related and lower respiratory symptoms (CARB 2008). Diesel trucks are the greatest contributor to these emissions, compared to trains, cargo handling equipment, and ocean going vessels. The Port's air quality goals include a reduction of excess community cancer risk caused from Port-related diesel particulate matter by 85% from 2005 to 2020. A major initiative to achieve this goal is to increase the amount of goods traveling by rail with the proposed Outer Harbor Intermodal Terminal on the former Oakland Army Base. As discussed above, this area is exposed to several sea level rise and storm event scenarios.

Environment
Port activities affect the surrounding environment with air emissions and noise. Any disruption caused by sea level rise and storm events could prompt other ports to accept more containerized goods. This could result in potential air quality, noise, and quality of life impacts on the environment near these ports, particularly if construction is necessary to upgrade and expand facilities.

Port property includes many sites that are contaminated with chemicals and substances toxic to human health and the environment. For example, soil and groundwater near Berths 25 and 26 are listed by the State of California as being contaminated with volatile organic compounds), polycyclic aromatic hydrocarbons, and metals. A Leaking Underground Storage Tank is located near the old Albers Milling Company site at Berth 30 and includes gasoline contamination, and former Oakland Army Base lands, contain significant amounts of metals, polychlorinated biphenyls, and total petroleum hydrocarbon. Rising groundwater, tidal inundation, and storm event flooding could cause the release of these contaminants, which could affect adjacent wildlife habitat.

Governance
Many government agencies contribute to the Port's operational and infrastructure decisions. As an autonomous department of the City of Oakland, the Port's Board of Port Commissioners has primary control over the planning and development of its landside infrastructure. However, any waterside development, including the expansion and renovation of its berthing facilities and piers and the maintenance/deepening of harbor channels, is regulated by a complex web of government agencies. The primary state and federal agencies and the laws they administer in permitting such port development projects are:

- San Francisco Bay Conservation and Development Commission administers the McAteer-Petris Act's requirement for permits that require Bay fill.

- United States Army Corps of Engineers regulates the placement of dredged and/or fill material into waters of the United States pursuant to the Clean Water Act. Also maintains the Port's primary federal channel.
- United States Environmental Protection Agency oversees disposal of dredged material and water quality pursuant to the Clean Water Act.
- San Francisco Bay Regional Water Quality Control Board administers permits for water quality pursuant to the Clean Water Act.
- State Lands Commission has ownership of all state tidelands subject to the public trust doctrine.

Additionally, the California Department of Fish and Game and United States Fish and Wildlife Service issue takings permits when state and federally listed endangered species are known to be affected by Port projects, as is the case with California Least Tern, salmonids, and herring in the Bay. To protect water quality and endangered species, the Port is only allowed to dredge in certain times of the year, known as "dredging windows" (LTMS 2001). The dredging window is August 1 through November 30 of any given year. Should the Port need to dredge outside of this window, it would need to engage in a lengthy permitting process through various resource agencies to ensure that aquatic habitats are not disturbed.

Thus, the seaport's ability to develop its infrastructure and protect against impacts from sea level rise and storm events is complicated if development requires filling or dredging of the Bay. Sea level rise may damage the Port's facilities and result in shorter operational life spans of critical infrastructure. The need for emergency repairs may also increase. With different infrastructure investment needs and timeframes, the current regulatory structure that dictates when and how to develop waterside seaport facilities may be inadequate to address future circumstances.

Key Findings

The majority of seaport facilities are only exposed to the more extreme scenarios of 55 inches of sea level rise with a storm event. Some infrastructure that is located under the wharves may be exposed earlier than the rest of the seaport. Due to its location and nature, this infrastructure is the most sensitive to storm events and may need to be moved as sea levels rise. Due to the life-cycle of seaport infrastructure, it is likely that most of the seaport facilities will be replaced or significantly rehabilitated prior to this exposure and could be designed to reduce or eliminate sea level rise and storm impacts. For these reasons, the seaport has low exposure and medium to high adaptive capacity, provided that the financing is available to replace and rehabilitate seaport facilities and factor in sea level rise and storms in those projects.

The primary vulnerability to the seaport will be to the rail system that moves cargo to and from the seaport and the roadways that surround the seaport. The seaport is only able to function if the rail and roadways that serve it are functional. Portions of both the rail and roadway systems serving the seaport are exposed to sea level rise at 16 inches and this exposure increases with a storm event. By 55 inches of sea level rise, the effects on system of rail and roadways that serve the seaport are much greater. So, while the seaport facilities are not exposed at the earlier scenarios and not very exposed at the later ones, the infrastructure that is critical to seaport function – rail and road – is exposed and therefore the seaport function is vulnerable.

The seaport serves a significant role in the economy and society of the region. It is the primary seaport in the region and creates a number of jobs and economic activity, both directly and indirectly. The Port of Oakland's seaport moves agricultural and perishable products out of the region, and California's agricultural industry relies on the seaport to move its goods. Any disruption to seaport operations would have a significant effect on the region and the state. The other seaports around the Bay Area – including Richmond, San Francisco, Redwood City – do not have the capacity to meet the demand met at Oakland's seaport and therefore, the system lacks redundancy.

It is important to recognize the societal and environmental consequences of flooding to the rail or roadway systems that serve the seaport. If the rail system were to be affected, this would result in an increased number of trucks necessary to move goods to and from the seaport. This would have effects on the residential and commercial areas that already face health and quality of life problems due to truck traffic and ancillary truck services through and in their neighborhoods, as well as increased congestion on the surrounding interstates such as Interstates 880, 238, and 80. A disruption to the roadway systems serving the seaport may require rerouting of truck traffic through neighborhoods not designed to accommodate such traffic.

References

Association of Bay Area Governments (ABAG). 2001. The Real Dirt on Liquefaction: A Guide to the Liquefaction Hazard in Future Earthquakes Affecting the San Francisco Bay Area. www.abag.ca.gov/bayarea/eqmaps/liquefac/Lq_rept.pdf.

California Air Resources Board (CARB). 2008. Diesel Particulate Matter Health Risk Assessment for the West Oakland Community. www.arb.ca.gov/ch/communities/ra/westoakland/documents/westoaklandreport.pdf.

Kuruvila, M. 2011. Oakland council acts to sink Occupy port blockades. *San Francisco Chronicle*, December 20, 2011.

Long Term Management Strategy (LTMS.) 2001. Long-Term Management Strategy for the Placement of Dredged Material in the San Francisco Bay Region - Management Plan 2001. http://www.spn.usace.army.mil/ltms2001/.

Martin Associates. 2011. The Positive Job Creation & Economic Impacts of the Port of Oakland. Presented September 8, 2011. http://www.portofoakland.com/poweringjobs/.

Port of Oakland. 2008. TCIF Funding Nomination for the Outer Harbor Intermodal Terminals (OHIT).

Port of Oakland. 2011. Strategic Plan, Fiscal Years 2011-2015. www.portofoakland.com/pdf/2011_pbs_06.pdf.

Rand Corporation. 2011. Assessing the Need for Adaptation: The Port of Los Angeles/RAND Corporation Study. Presented January 27, 2011.

Tioga Group. 2009. SF Bay Area Containerized Cargo Outlook. Prepared for San Francisco Bay Conservation and Development Commission, July 2009.

Vera, R. 2009. Impacts and Responses to Sea Level Rise at the Port of Los Angeles. Masters Thesis in Urban and Regional Planning, California State Polytechnic University, Pomona.

Chapter 11. Ground Transportation

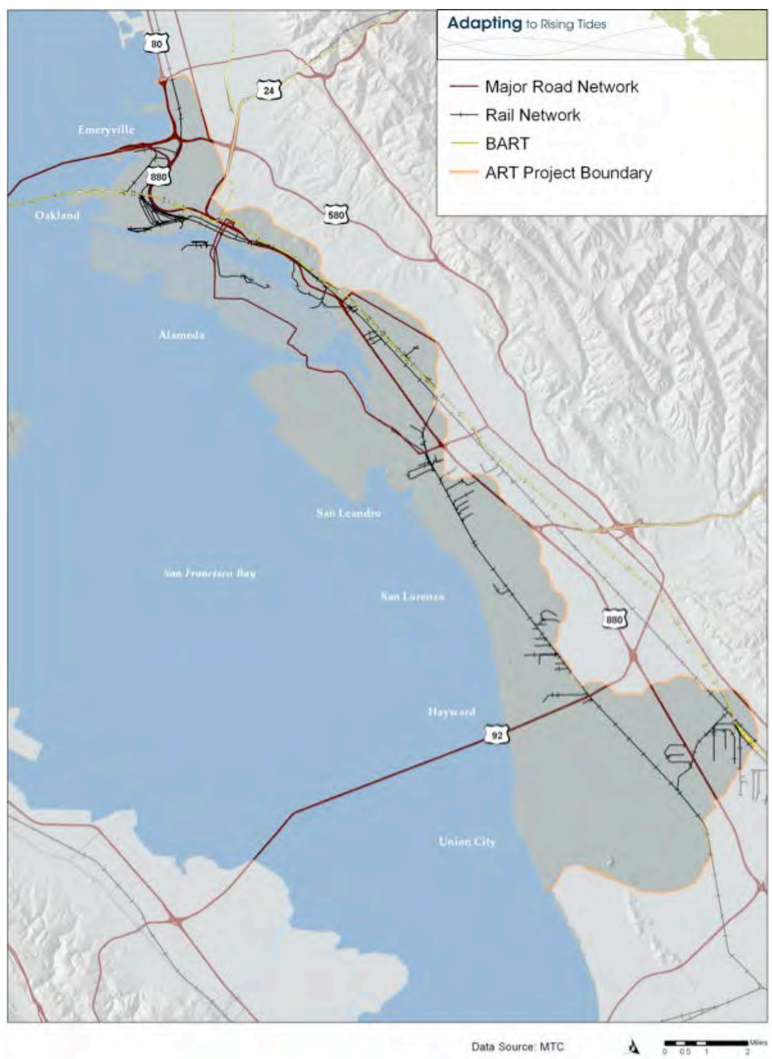
The ART project area is home to a number of critical transportation modes that are part of a system that connects and serves the greater Bay Area. These include Interstate highways and local roads, Bay Area Rapid Transit (BART) passenger rail system, commuter and freight rail, and the trans-bay ferry network. All of these modes could be affected by the prospect of a changing climate, whether due to daily tidal inundation, storm event flooding, or elevated groundwater. Each transport mode is different in both form and function, and consequently will respond differently to sea level rise and other climate impacts.

This chapter presents an overview of these transportation categories and examines their ability to adapt to sea level rise under forecasted scenarios. The information is drawn from an analysis conducted by AECOM and Arcadis for the Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project (AECOM, 2011), including data on use levels of various transportation assets (unless otherwise cited).

Roadways

Three major interstates and several highways are located within the ART project area (Figure 1), connecting it to the employment centers in San Francisco and the Peninsula and to the Oakland International Airport and the Port of Oakland's seaport. These are: Interstate 80/580 (Eastshore Freeway), Interstate 880, Interstate 980, California State Highway 92 (CA-92), and California State Highway 61. Interstate 80/580 and Interstate 880 serve as primary connections to the San Francisco-Oakland Bay Bridge (Bay Bridge), the only bridge that crosses directly into the City and County of San Francisco from the East Bay. More than 212,000 vehicles use Interstate 880 to travel throughout the East Bay on an average day. Interstates 80 and 580 connect to other highway and interstate systems that serve both the county and the region. Interstate 80 links San Francisco to the national network of Interstate highways, while Interstate 880 provides a regional connector for the movement of people and goods between Oakland International Airport, the Port of Oakland, and CA-92. CA-92 runs the length of the San Mateo-Hayward Bridge and is used by 86,000 vehicles every day. The San Mateo-Hayward Bridge (San Mateo Bridge) provides commuters a connection between the East Bay and the Peninsula, a significant

Figure 1. Overview of ground transportation assets in the ART project area



employment center in the Bay Area and home to Silicon Valley. The San Mateo Bridge also provides an alternative bridge route in the event of Bay Bridge closures. During the recent closures for the Bay Bridge seismic retrofit, for example, the San Mateo Bridge served as a primary alternative for East Bay commuters to travel into San Francisco.

Three major roads serve Oakland International Airport (one of three international airports in the Bay Area and the only one in the East Bay) and connect it to Interstate 880: Hegenberger Road; 98^{th} Avenue, and California Highway-61. All of the major access roads meet up to form Airport Drive, the major road in and out of the airport's passenger terminals.

There are several primary routes serving the Port of Oakland's seaport, including Interstate 880, Interstate 80/580, Interstate 580 East, Interstate 80 East, and Interstate 980. The Port of Oakland is the primary seaport in the region, exporting agricultural goods and importing machinery, electronics, and apparel.

Interstate 80/580 serves and passes through the City of Emeryville, and Interstate 880 serves and passes through the cities and communities of Oakland, San Leandro, San Lorenzo, Hayward, and Union City. Interstates 880 and 980 provide access to the City of Alameda, which is an island west of the City of Oakland. The island is connected to downtown Oakland through a set of two one-way tunnels (Webster and Posey Tubes), while three bridges (Park Street, Fruitvale Avenue, and High Street) connect the city to other parts of Oakland. Bay Farm Island, a mainland residential area within the City of Alameda, connects to the island portion of Alameda via a parallel pair of a pedestrian/bicycle and vehicular bridges.

Buses

The majority of bus routes in the ART project area are operated by AC Transit, an Oakland-based public transit agency serving the western portions of Alameda and Contra Costa Counties. With a few exceptions, most of AC Transit's bus routes share identical rights-of-way with private automobiles. As of August 2011, AC Transit's 364 square mile service area consists of a total of 116 bus lines: 71 of these are local lines within the East Bay; 34 are Transbay lines that cross the Bay Bridge and provide service to San Francisco, as well as one line that crosses the San Mateo Bridge to the Peninsula; and 6 are All-Nighter lines that provide a viable means of regional transportation during the late-night hours when rail services do not operate.[1] Average daily weekday ridership was approximately 200,000 in the 2009-2010 Fiscal Year, 60,000 of those being school children.

Some of AC Transit's busiest routes travel through ART project areas that are vulnerable to sea level rise and storm events. For example, Lines 72/72M/72R (average of 8,049 daily passengers (AC Transit 2008)) all travel through the same low-lying sections of Oakland and Alameda. Line 97 (average of 5,140 daily passengers (Ibid.)) travels through vulnerable areas in the cities of San Leandro, San Lorenzo, Hayward, and Union City. Other bus lines rely on isolated routes and have no feasible detour in the event of flood-related closures. The Transbay bus lines, for example, accommodate an average total of 14,000 commuters but use the Bay Bridge and rely on a limited number of accessible on-ramps to operate. Some of the less popular bus lines serve isolated communities that are both economically and physically sensitive to the impacts of inundation. These include: AC Transit Lines 314 (estimated 44 average daily passengers in 2008 (Ibid.)) and 356 (estimated 62 average daily passengers in 2008 (Ibid.)), which run along many stretches of vulnerable road through low-lying sections of Oakland; AC Transit Route 86, serving the low-lying areas of Hayward; and AC Transit Route 89, which runs through low-lying sections of San Leandro.

[1] http://www.actransit.org/about-us/facts-and-figures/ridership/

Other bus services in the ART project area include those operated by cities, such as the Emery Go Round, serving to connect destinations in and near Emeryville; the Broadway Shuttle in the City of Oakland; shuttles to and from the airport operated by a number of organizations; and Union City Transit, which provides service within Union City. Many of these bus routes provide service within low-lying areas and for transit-dependent communities that are not only vulnerable to SLR and storm events but are susceptible to very high levels of liquefaction during seismic events.

Bicycle Routes

Bicycling is a popular mode of transportation in the ART project area. People use bicycles to commute and for recreation along a variety of routes. These routes include roadways, some of which are labeled as bike routes and marked either with separate bike lanes or "sharrows," (Figure 2) as well as separate trails that cannot be used by cars, but may be shared with pedestrians. The Bay Trail includes both roads and separated trails, and is a popular corridor for bicyclists. Within the ART project area, there are 74 miles of existing and proposed Bay Trail between Emeryville and Hayward, connected to a larger continuous regional trail system around the edge of the Bay. Other trails such as the Lake Merritt connector trail connect with the Bay Trail.

Figure 2. "Sharrows" on pavement and bike route sign

BART

While the ART project area is home to a critical network of Bay Area interstates and highways, it also has one of the busiest rapid transit systems in the United States. BART, or Bay Area Rapid Transit, is a heavy-rail public transport network that accommodates an average of 365,000 weekday boardings (MTC 2011) and connects cities throughout northern San Mateo County, the City and County of San Francisco, and the East Bay. It consists of five lines, all of which travel through the ART project area. Four of the five lines cross the Bay through the Transbay Tube, an underwater section of tunnel below the San Francisco Bay that is partially within the ART project area. The Transbay Tube provides a way for residents within the ART project area and the San Francisco Peninsula to commute across the Bay as an alternative to traveling over the San Francisco-Oakland Bay Bridge by automobile or bus, or on the Bay by ferry. The ART project area contains three BART stations, which include: *West Oakland* (approximately 10,700 daily entries/exits), served by all of BART's lines except for the Richmond-Fremont line; *Lake Merritt* (approximately 11,000 daily entries/exits[2]), served by the Richmond-Fremont, Daly City-Dublin/Pleasanton and Daly City-Fremont lines; and *Coliseum/Oakland Airport* (12,000 daily entries/exits), served by the same lines as the Lake Merritt station.

Regional Rail Links

The ART project area also contains rail service that connects the greater Bay Area. Amtrak, the national railway network, terminates California Zephyr service at the Emeryville Station, while the Capitol Corridor, Amtrak's Northern California regional service, connects the Bay Area to the state capitol of Sacramento and the Sierra Nevada foothills. The Capitol Corridor is currently Amtrak's fourth busiest rail line (Amtrak 2011) and continues south through the ART

[2] http://www.bart.gov/docs/WeekdayExits.pdf

project area along at-grade railroad tracks that run roughly parallel to Interstate 880. These railroad lines are also used by national freight carriers, such as Union Pacific and the Burlington Northern Santa Fe, to deliver goods from the Port of Oakland to destinations throughout the state and across the country.

Ferry Network
The Bay Area ferries, once the dominant method of travel between San Francisco and the East Bay, now play a much smaller but nevertheless important role in the Bay Area transportation network. Three ferry terminals lie within the ART project area: the Jack London Square terminal (located close to Amtrak's rail station and downtown Oakland), the Alameda Ferry Terminal in the City of Alameda, and the Harbor Bay Ferry Terminal on Bay Farm Island. All of these terminals have service to and from San Francisco's Ferry Building and will begin to provide service to the South San Francisco Ferry Terminal in June 2012. Ferries within the ART subregion are operated by the Blue & Gold Fleet for the Water Emergency Transportation Authority, with one line serving the Jack London Square and Alameda terminals, and a separate line, which operates only on weekdays, serving the Harbor Bay Ferry terminal.

Exposure

Exposure is the extent to which an asset experiences a specific climate impact such as storm event flooding, tidal inundation, or elevated groundwater. The exposure of selected ground transportation assets in the ART project area to two sea level rise projections and three Bay water levels was evaluated. The two sea level rise projections, 16 inches (40 cm), and 55 inches (140 cm), correlate approximately to mid- and end-of-century. These two sea level rise projections were coupled with three Bay water levels: the new daily high tide, measured as mean higher high water (MHHW), the new 100-year extreme water level, also known as the 100-year stillwater elevation, and the 100-year extreme water level coupled with wind waves, hereafter "storm event with wind waves," or "wind waves." These water levels were selected because they represent a reasonable range of potential Bay conditions that will affect flooding and inundation along the shoreline. For each exposed facility, the average depth of inundation from the daily high tide and storm events was calculated. Whether a facility is exposed to wind waves was evaluated as a simple binary – yes or no. For more information about sea level rise projections and Bay water levels evaluated see Chapters 1 and 2.

Exposure was analyzed by network type, such as roadways or railroad, and also by individual, point-based asset, such as a single station (see Appendix C). For network type, exposure is calculated in mileage (i.e., the length of roadway or track for which inundation occurs for a specific category of transportation). For individual assets such as rail and BART stations, the average depth of inundation in each exposed facility footprint was calculated.

Exposure by Network Type
Roadways are classified by Functional Road Class (FRC), designations developed by the digital map company Tele Atlas to classify roads by the level of travel mobility that they provide relative to the overall United States road network (Table 1). Exposure of the road network in the ART project area was conducted for the extent of roads in each FRC. The 120 miles of regional rail (e.g., Union Pacific, Amtrak) in the ART project area were also evaluated to determine the mileage of railroad exposed to each scenario.

While GIS data was available for the alignment of roads and rail, elevation data – that is, whether various road and rail segments are below, at, or above grade – was not available. For certain critical road segments that are clearly below-grade, such as the entrance to the Posey and Webster Tubes connecting Oakland and Alameda and well-known underpasses and overpasses, more precise conclusions regarding their exposure were drawn. Other segments are assumed to be at grade, so further analysis is necessary to more precisely determine the exposure to different Bay water levels.

For BART, analysis using just the alignment data would not be very useful because track elevation varies so dramatically and is rarely at grade in the ART project area. However, BART is conducting its own exposure analysis using more detailed information, including track elevation. Therefore, while BART stations are included in this analysis, exposure of BART tracks is not included here.

Table 1. Tele Atlas road categories with local equivalents in the ART project area

Tele Atlas Road Class	Classification Description*	Miles of FRC in ART project area	Local Examples
FRC 0	Limited-Access Highways	70	Interstate 880
FRC 1	Major Roads	8	CA-92 (San Mateo Bridge)
FRC 2	Regional Connectors	0	CA-24
FRC 3	Secondary Roads	33	CA-61 / Doolittle Drive
FRC 4	Local Connectors	144	Hegenberger Road
FRC 5	Local Roads of High Importance	187	Broadway

*Classification descriptions from U.S. Highways and Major Roads, Pitney Bowes, Version 2011
http://reference.mapinfo.com/Data/USHighways/2011/USHighways_ProdGuide_2011.pdf

With 16 inches of sea level rise, a five-mile portion of local roads with high importance (FRC 5), will be inundated by the new daily high tide. During a storm event twenty-two more miles of local roads of high importance will be inundated, along with up to four miles of limited-access highways, seven miles of secondary roads, and eight miles of local connectors. With wind waves, nearly 200 miles of roadways across all classifications could be affected. Bus and bicycle routes along these corridors would also be exposed, as well as some roadway connections to ferry terminals and BART stations. None of the railroad in the ART project area will be exposed to the daily high tide, but 5 miles will be exposed to storm event flooding, and 60 miles could be exposed to wind waves (Table 2).

With 55 inches of sea level rise, 98 total roadway miles and 22 railroad miles will be exposed to inundation by the new daily tide. During a storm event, nearly 200 miles of the roadway network, and 61 miles of the railroad network in the ART project area will be flooded, with 267 miles of the road network exposed to wind waves, and 83 miles of rail exposed. The greatest share of roads exposed is made up of local roads of high importance such as downtown streets. The bus and bicycle routes along these corridors would also be exposed, as well as some of the roadway connections to ferry terminals and BART stations.

Table 2. Exposure of road and rail network to daily high tide and storm events with 16 and 55 inches of sea level rise. All facilities exposed to storm event flooding are also within the wind wave zone. Therefore, the mileage indicated as being exposed to wind waves only does not include the miles exposed to storm event flooding but includes all additional miles exposed to a wind wave scenario.

	16" SLR			55" SLR		
	Daily High Tide	Storm Event		Daily High Tide	Storm Event	
System Category	**Miles exposed**	**Miles exposed**	**Miles exposed to wind waves only**	**Miles exposed**	**Miles exposed**	**Miles exposed to wind waves only**
Roadways: Limited-Access Highways (FRC 0)	0	4	25	16	29	16
Roadways: Major Roads (FRC 1)	0	0	3	1	3	1
Roadways: Regional Connectors (FRC 2)	0	0	0	0	0	0
Roadways: Secondary Roads (FRC 3)	0	7	5	8	12	2
Roadways: Local Connectors (FRC 4)	0	8	50	24	58	23
Roadways: Local Roads of High Importance (FRC 5)	5	27	64	48	91	26
Total length of roadways exposed	**5**	**45**	**149**	**98**	**194**	**68**
Regional Railroads: System-Wide	**0**	**5**	**55**	**22**	**61**	**22**

Exposure by Representative Asset

The following section analyzes the exposure of selected, representative, ground transportation assets, such as a rapid transit station, ferry terminal, or a specific section of railroad track. The assets are divided into two categories: public transportation and road and rail network assets. Public transportation assets include BART and Amtrak Capitol Corridor Stations, ferry terminals, and a selected section of Amtrak rail, and are displayed in Table 3. Road and rail network assets are specific sections of road and rail (not passenger rail) selected for analysis because they are major routes near the shore. Exposure of these assets is shown in Table 4.

Public Transportation

With 16 inches of sea level rise, none of the selected public transportation assets are exposed to the daily high tide, with the exception of those dependent upon exposed roadway segments such as bus routes, bicycle routes, and roads serving ferry and rail stations. During a storm event, the Union Pacific Martinez Subdivision would be flooded up to a foot. This Subdivision, both BART stations, both ferry terminals, and the Jack London Square Amtrak station are exposed to wind waves during a storm event.

With 55 inches of sea level rise, most of the selected public transportation assets are not exposed to inundation by the daily high tide, except for several assets in Oakland including the railroad subdivisions of Union Pacific Niles (located in Oakland and Union City within the subregion) and Union Pacific Martinez, and the Jack London Square Ferry Terminal. During a storm event, all facilities except for the ferry terminals would be inundated by several feet, with a maximum of ten feet at the Jack London Square Amtrak Station. All of the selected assets are exposed to wind waves during a storm event.

Table 3. Exposure of representative public transportation assets to the daily high tide and storm events with 16 and 55 inches of sea level rise. None of the representative assets are exposed to the daily high tide or storm event with 16 inches of sea level rise. All assets exposed to storm event are also within the wind wave zone and could experience deeper inundation than estimated because Bay water levels increase when there are wind waves.

	16" SLR	55" SLR		
	Storm Event	Daily High Tide	Storm Event	
Public Transportation Asset	Exposed to wind waves only	Average depth (ft)	Average depth (ft)	Exposed to wind waves only
BART: West Oakland Station			1	
BART: Coliseum/Oakland Airport Station	Yes		1	
RAIL: Amtrak Emeryville Station				Yes
RAIL: Amtrak Jack London Square Station	Yes	1	1	
RAIL: Amtrak railroad between Coliseum Station and 98th Avenue	Yes	1	1	
FERRY: Jack London Square Terminal	Yes		2	
FERRY: Alameda Main St. Terminal (Park & Ride, Bicycle, and ADA)	Yes	1	3	
FERRY: Alameda Harbor Bay Terminal	Yes		2	

Roads and Rail

With 16 inches of sea level rise, most of the selected sections of the road and rail network within the ART project area will not be exposed to the daily high tide. The sole exception is the SR-260 Posey Tube approach in Alameda, which would be inundated up to four feet by the new daily high tide. During a storm event, most of these selected sections would be flooded, with very high water levels concentrating around the underpasses of the Posey and Webster Tubes in Alameda (22 feet of inundation) and Airport Drive (26 feet of inundation) near Oakland International Airport. Such high depths are generated in this forecast because these stretches of road include underpasses that travel below ground level and slope downward. Airport Drive, for example, will be completely impassable with 16 inches of sea level rise under stormy conditions because the 98th Avenue / Doolittle Drive underpass travels below ground level and will collect significant amounts of water. Such physical vulnerabilities are emphasized in greater detail in the Sensitivity and Adaptive Capacity section of this report. Additionally, the approaches to the Bay Bridge toll plaza are exposed during a storm event, as are several sections of Interstate 880 that pass through the City of Oakland.

With 55 inches of sea level rise, the approaches to the Bay Bridge toll plaza are exposed to the new daily high tide, as is the Bay Farm Island Bridge and the majority of Oakland International Airport's access roads. The majority of Oakland International Airport's major access roads not listed in the exposure charts are vulnerable to flooding in a 100-year storm event. Hegenberger Road, the major street in Oakland where most of Oakland International Airport's hotels and services lie, will be inundated along its entire stretch from the airport terminals to Interstate 880. Hegenberger Road's other alternate access routes, 98th Avenue and CA-61/Doolittle Road, will also be flooded in a 100-year storm event. More specific details on the impacts of sea level rise on the ground transportation network around Oakland International Airport are summarized in the airport section of this report.

The Bay Trail, an important bicycle route, is already affected by flooding. Portions of the trail have been temporarily closed or damaged due to extreme weather events. With 16 inches of sea level rise, a majority of the trail south of Marina Park in San Leandro would be affected by storm event flooding. With the exception of the Bay Trail around San Leandro Bay (in Martin Luther King Jr. Regional Shoreline), the majority of the trail in the northern portion of the ART project area is unlikely to experience significant impacts with 16 inches of sea level rise. In the longer term, most of the Bay Trail in the ART project area will be fully inundated or impaired by flooding with 55 inches of sea level rise. This includes portions of the Bay Trail on local roads, such as Harbor Bay Parkway, Doolittle Drive, Union City Boulevard, and Mandela Parkway. The Lake Merritt connector trail and the Hayward Shore Recreational Area Trail are exposed to all impacts, including the daily high tide with 16 inches of sea level rise.

Table 4. Exposure of representative road and rail network assets to the daily high tide and storm events with 16 and 55 inches of sea level rise. Assets exposed to storm event flooding are also within the wind wave zone and could experience deeper inundation than estimated because Bay water surface levels increase when there are wind waves.

	16" SLR		55" SLR	
	Daily High Tide	Storm Event and wind waves	Daily High Tide	Storm Event and wind waves
Road Section	Average depth (ft)	Average depth (ft)	Average depth (ft)	Average depth (ft)
I-80: Powell St. to Bay Bridge Toll Plaza		2	3	5
I-80: Bay Bridge from Toll Plaza to Alameda County Line		2	2	5
I-880: Oak St. to 23rd Ave.		1	1	4
I-880: High St. to 98th Ave.		2	3	5
SR-260: Posey Tube (Alameda Portal)	4	22	23	25
SR-61: Webster Tube (Alameda Portal)		22	23	25
Alameda: Bay Farm Island Bridge			1	4
SR-92: Clawiter Rd. to San Mateo Bridge				3
OAK: Airport Dr.		26	27	29
Hegenberger Rd: From San Leandro St. to Doolittle Dr.		2	3	5
RAIL: Union Pacific Martinez - 34th St. to 10th St.			3	5
RAIL: Union Pacific Niles - Magnolia to East Oakland Yard		1	2	4

Sensitivity and Adaptive Capacity

The sensitivity and adaptive capacity of ground transportation assets was assessed for three potential climate impacts that could occur due to sea level rise and storm events. The three climate impacts considered are:

- More frequent floods or floods that last longer due to storm events
- Permanent or frequent inundation by the daily high tide
- Elevated groundwater levels and saltwater intrusion

Sensitivity is the degree to which an asset or entire system (e.g., rail or roads) would be physically or functionally impaired if exposed to a climate impact. Adaptive capacity is the ability for an asset or system to accommodate or adjust to a climate impact and maintain or quickly resume its primary function. The sensitivity and adaptive capacity of ground transportation was evaluated, considering not just physical sensitivity, but also functional sensitivity as it relates to commuter and goods movement.

Primary Roadways and Bridges

Some portions of the roadway network in the ART project area are more sensitive than others to sea level rise and storm events because they vary in type of structure, elevation, or drainage, or are simply the only routes available to access community and regional assets such as residential communities, the airport, job centers, and other critical facilities.

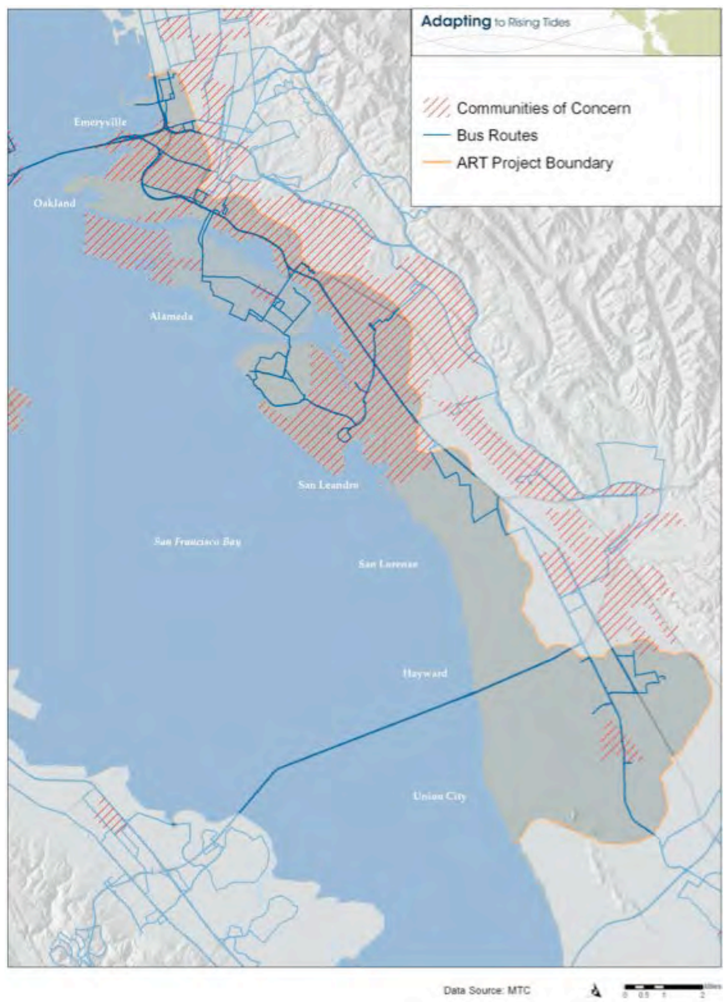
Tunnels and underpasses are more sensitive to flooding because their approaches are below sea level. For example, the twin Alameda Tube entrances are highly sensitive to inundation because their approaches travel below grade into tunnels below sea level. Within these tunnels, the access and departure ramps from Alameda show greater exposure to rising water levels than the approaches on the Oakland side. With 16 inches of sea level rise, the Webster Tube departure in Oakland is not inundated by the new daily high tide but the Posey Tube approach in Alameda is exposed to inundation levels of approximately four feet.

The surface-level on-ramps from the southbound Eastshore Freeway to the Bay Bridge Toll Plaza are the only on-ramps to the Bay Bridge Toll Plaza from Interstate 80 West and Interstate 580 South, two major interstates serving the region. Any type of disruption to these structures would have significant impacts on regional, state, and national passenger and cargo travel. Otherbridges, BART, and ferry routes would not have the capacity to serve as long-term alternates to the Bay Bridge. Although BART lines provide frequent daily service, departures are limited in the early morning, late evening, and weekends; there is no regular late night service, and the system does not have the capacity to meet current ridership levels as well as those displaced from Bay Bridge automobile and bus traffic. While the ferry system has been augmented to serve as an alternative to the Bay Bridge during past disruptions, it lacks the capacity to serve those displaced from the Bay Bridge and does not provide late night service. Due to reduced BART and ferry service outside of regular commute hours, these services would have to be increased, or disruptions to the Bay Bridge on-ramps would affect those who travel the Bay Bridge corridor during non-commute hours significantly.

Other high-traffic, limited-access corridors facilitate the movement of goods, people, and visitors throughout the entire region. For example, Interstate 880 provides a route that connects residents in the East Bay to jobs and the airport. With 16 inches of sea level rise, one segment of Interstate 880 (High Street to 98th Ave.) could be inundated up to two feet by storm event flooding. As previously noted, one foot of water is considered sufficient to render a roadway impassable. When closures occur on these roads, traffic could be bypassed through numerous local roads, but this could overwhelm local roadways and communities. Some assets could become completely isolated due to the inundation of roads for which there are no alternative routes or public transport options.

Oakland International Airport relies on low-lying roads from all directions for terminal access. With 16 inches of sea level rise, most of the airport's access roads from Alameda (Ron Cowan Parkway, Harbor Bay Parkway, and Doolittle Drive) would be inundated by storm event flooding. With 55 inches of sea level rise, inundation due to storm events is expected along Oakland International Airport's main access roads to Interstate 880 (Hegenberger Road / 98th Avenue / Doolittle Drive). By mid-2014, however, some of these access problems will be mitigated by the completion of a new, elevated Automated Guide Transit (AGT) system between Oakland Airport and the Oakland Coliseum BART station known as the Oakland Airport Connector. The Oakland Airport Connector would provide a viable above-grade alternative for Bay Area travelers in the event that local access roads are inundated.

Figure 3. Communities of Concern in the ART Project Area



Bus lines and bicycle routes often share the same stretches of roadway as automobiles and provide critical alternatives for those who do not own cars. All of the routes mentioned earlier in this report (Lines 72/72M/72R, 97, 314, 356, 86, 89) run through low-income and transit-dependent communities, classified as "Communities of Concern" (Figure 3) by the Metropolitan Transportation Commission (MTC).[3] Other AC Transit services, such as those within the Transbay network (B, F, NL, O, OX, SB, W, 800), also travel through such communities. Some of MTC's Communities of Concern are located within the ART project area, including western Alameda Island; the City of Oakland south of Interstate 580; Emeryville west of Interstate 80; and Union City east of CA-238 – these areas are highlighted in Figure 3.

Among all of these routes, adaptive capacity will vary depending on the intensity of localized climate impacts. The routes with the least adaptive capacity are popular lines that not only serve transit-dependent communities but also run along isolated routes that will likely become inundated with sea level rise. The majority of the

[3] MTC's "Transportation 2035 Plan for the San Francisco Bay Area" includes an Equity Analysis Report that divides the region into zones defined by minority populations, poverty, or both, and emphasizes the importance of access to transit for those who do not have cars and for "communities of concern" (MTC 2009).

bus lines identified in this report are within this category, including the Transbay bus routes (B, F, NL, O, OX, SB, W, 800).

BART

While many rail structures within the BART network run along elevated routes over inundated portions of the ART project area, the track consists of fixed electric third-rail routes that are minimally protected from the elements and are highly sensitive to climate-related impacts. Within BART's various tracks and stations, many less visible infrastructure components keep BART functioning, including tunnels, ventilation tubes, and control centers. This infrastructure is often located underground and is vulnerable to water at ground elevation; many vents are connected to the sidewalks and only need a small amount of rain to begin to flood (Figure 4).

Lake Merritt Station is one example where such critical assets are at risk. Although this station is not at risk of inundation in the sea level rise scenarios considered in this report, BART officials have identified it as being subject to groundwater intrusion due to a high water table. The station is situated near Lake Merritt, a body of water connected to the San Francisco Bay via a canal that passes directly over a BART tunnel. Groundwater intrusion has already caused corrosion of some structural members in the below-grade parts of Lake Merritt station, which is currently protected by a sump pump. The major operational impacts of additional water intrusion due to sea level rise are unknown, but it is possible that storm event flooding could close some station entrances or the entire station should the capacity of sump pumps be exceeded. The other two BART stations in the subregion – West Oakland and Coliseum/Oakland Airport – are both exposed to storm event flooding with 55 inches of sea level rise.

In addition to station flooding, rising groundwater levels may increase the likelihood and extent of liquefaction, which could damage BART's underground structures during a seismic event. According to ART project data, the eastern portal of the Transbay Tube is located in an area that is highly prone to liquefaction. Tunnel leaks could potentially occur within the structure after a seismic event due to the unstable nature of the soil.

Figure 4. Example of BART street-level subway vents along Market Street, San Francisco (Source: http://nikdaum.com/news/10sf540big.jpg)

The high cost of heavy rail construction limits BART's adaptive capacity to cope with sea level rise relative to other more flexible modes of public transportation, such as buses. Should flooding or tidal inundation necessitate relocation, the majority of BART's network would be difficult to move or reconstruct due to a lack of available land and the high cost of constructing and maintaining a heavy rail system. Unlike buses or other forms of vehicular transportation, BART lines operate on fixed rail; in other words, any kind of inundation of BART's rail line on the ground could also interrupt service on its elevated structures, or possibly the entire BART network. Moreover, BART lines are very expensive to construct;

while highway construction in dense urban areas costs an average of $7-15 million per mile[4], recent BART extensions have been estimated at over $200 million per mile[5].

Regional Rail Links
Similar to BART, other regional rail links such as the Capitol Corridor and the Union Pacific Martinez and Niles subdivisions also have limited adaptive capacity because they cannot be easily reconstructed or relocated, and a localized impact in the system could affect the entire network's ability to function. One major difference between the Capitol Corridor and BART is that most stretches of rail in the ART project portion of the Capitol Corridor are at-grade and close to the shoreline, resulting in a very high level of sensitivity to sea level rise.

Portions of both the Union Pacific Martinez subdivision in the north and Niles subdivision in the south will be inundated between four to five feet with 55 inches of sea level rise during a storm event. Storm event flooding on portions of the Niles subdivision begin to occur with 16 inches of inch sea level rise. This rail infrastructure is not only the most vulnerable to sea level rise but is also the only link for trains in the Capitol Corridor system to reach the lower East Bay from northern East Bay communities. This means that even if significant portions of the rail network were not sensitive to flooding impacts, immediate work would have to be performed on the inundated sections of rail in order for the entire network to function. Additionally, the Capitol Corridor is supported by an operations and maintenance facility that adjoins the Union Pacific Niles Subdivision in Oakland and is highly susceptible to liquefaction and will be exposed to the daily high tide and storm events with 55 inches of sea level rise. No adequate alternative is available for this asset, given both its location and function in an isolated area of railroad tracks. Therefore, adaptive capacity for the Capitol Corridor's maintenance facilities is limited and could jeopardize the ability of the entire system to run at full system capability.

Figure 5. Alameda / Oakland Ferry docked in Jack London Square (Source: http://en.wikipedia.org/wiki/File:Alameda Oakland Ferry.JPG)

Ferry Network
Ferry piers, when viewed as independent assets, are not very sensitive to sea level rise because they are highly adaptable to the daily rise and fall of the tide (Figure 5). Additionally, ferry piers appear not to be exposed directly to sea level rise because they are situated high enough above current Bay level and beyond the shoreline. Damage caused by storm events to the portions of the piers that are exposed to waves could be an

[4] http://www.railstotrails.org/resources/documents/whatwedo/policy/07-29-2008%20Generic%20Response%20to%20Cost%20per%20Lane%20Mile%20for%20widening%20and%20new%20construction.pdf
[5] http://www.bayrailalliance.org/q_why_not_replace_caltrain_bart_wont_cost_same_ele

issue for some of the ferry terminals. Ferry piers are also highly affected by changing weather conditions and access from nearby roads. Ferry piers are more sensitive to high winds than the ground transport networks discussed in this report because such events significantly affect the safe docking and operation of ferries. Even with today's sea level, ferry service has occasionally been suspended during storms.

Roadway access to the ferry terminals is highly sensitive to climate impacts because access roads travel through low-lying areas. Ferry piers are obviously dependent on water, and therefore access roads must run close to the shoreline. More specifically, access roads for the Alameda Ferry Terminal are located in disconnected low-lying areas behind man-made flood protection features. These roads would be especially vulnerable to overtopping because they lie at a lower elevation than the San Francisco Bay. Their inundation would prohibit passengers from accessing the ferry piers.

The access roads to the Jack London Square Ferry Terminal and the Alameda Gateway Ferry Terminal would be flooded in a storm event with 16 inches of sea level rise. There are only a few other pier structures in the area, which leaves limited options for ferry operators to embark or disembark passengers at alternate docking locations. Likewise, if the main ferry piers were to become damaged by storms, the system's ability to function would be affected.

Consequences

The potential consequences of daily tidal inundation, storm event flooding, or elevated groundwater on the ground transportation network in the ART project area must be considered for both the physical infrastructure and the functional purpose that infrastructure serves within the communities and the subregion. Consequences are the magnitude of the social, economic, legal, and environmental effects if an impact occurs. Factors that inform the magnitude of the potential consequences include the severity of the impact on community and regional mobility, the cost of responding to the impact by either repairing or replacing the exposed infrastructure, the size and demographics of the population served by the exposed infrastructure, the type of natural resources affected, and the cost of the disruption to the economy of the subregion and region.

<u>Economy</u>

A number of key road and transport routes in the ART project area run through areas that could be inundated as a result of sea level rise. Interstate 880 is a major corridor that connects several regionally and nationally important facilities along its route. These include the Oakland International Airport, the Port of Oakland, Oracle Arena, and the Oakland/Alameda County Coliseum. It is one of the busiest transportation corridors in the Bay Area, with an average annual daily traffic of 226,000 vehicles in the corridor between Oak Street and 23rd Avenue, and 212,000 vehicles in the corridor between High Street and 98th Avenue. A large amount of truck traffic (10.3% of total daily use[6]) depends on Interstate 880 to transport goods, especially from the Port of Oakland, as there are trucking restrictions on Interstate 580 (a parallel interstate that is located to the east of the ART project area along the East Bay hills). Any inundation of one foot or more along Interstate 880, therefore, could interrupt the transport of goods and translate into enormous economic losses for the Port of Oakland and the Bay Area economy. During a 2002 contract dispute, for example, a work slowdown at West Coast ports cost the U.S. economy an estimated $1 billion to $2 billion per day (Heberger et al. 2009).

Other corridors could also be affected by sea level rise. For example, the surface-level approaches from Interstate 80/580 to the Bay Bridge Toll Plaza will be inundated with 16 inches

[6] http://i880corridor.com/index.php/about-the-project/faqs

of sea level rise, and because there are few alternatives this could affect more than 250,000 passenger vehicles that use this route each day. The Transbay bus network uses the same approaches to access the Bay Bridge. More than 27 bus routes use the Bay Bridge, carrying a total of around 14,000 daily passengers.[7] Temporary disruption of these routes would mean that these passengers would have to rely on alternative forms of transport to commute across the San Francisco Bay, whether it is via BART or via automobile on an alternative bridge crossing.

Other important road and transport routes that could be affected by sea level rise include roads that travel below ground level. In Alameda, a closure of the Webster and Posey Tubes would lead to increased congestion on its smaller overland bridges which do not have the capacity for the average daily number of trips on and off the island. Approximately 22,300 vehicles and 18,333 transit riders use the tubes daily, and they provide a quick connection from Alameda to downtown Oakland, including the Jack London Square Ferry Terminal and the Amtrak station. One of AC Transit's busiest bus lines, Line 51A (with 11,445 average daily passengers), travels through the tubes. Closure of either of these tubes could mean that all forms of transport would be redirected to the bridges, meaning greater delays and losses in economic productivity.

Another critical belowground transportation asset is BART's Transbay Tube, which connects the East Bay with San Francisco under the Bay along the same general corridor as the Bay Bridge. In the event of a Transbay Tube closure, the entire BART network would be affected because there is no other alternative for trains to connect San Francisco with the East Bay. Four out of the five lines in the BART system use the Transbay Tube, which carries about half of the system's 365,000 daily weekday riders (Alameda Patch 2012). Without the Transbay Tube and BART service along this corridor, the Bay Bridge and other area bridges would likely experience a sharp rise in congestion and use, and the economic and social impacts of the loss of BART service would be significant.

<u>Society</u>
Sea level rise could have a serious effect on residents identified by MTC as Communities of Concern in the ART project area, especially for transit dependent residents who rely on local bus lines for their commute. For transit-dependent individuals in these areas, assistance may be needed to compensate for lack of access to services and jobs. Such assistance would be needed the most under stormy conditions. During significant storm events such as Hurricane Andrew, for example, low-income communities have been unable to evacuate due to lack of financial means to buy supplies or transportation (Heberger et al. 2009). If Communities of Concern in the ART project area are flooded, these communities could become temporarily isolated, translating into a loss in local economic productivity and reduced public safety.

<u>Environment</u>
The environmental consequences of ground transportation are largely related to air and water quality. Vehicle emissions cause local air pollution, and oil and other fluids used in vehicles can be washed off of roadways into local water bodies. The exposure of ground transportation assets could cause an increase in certain types of transportation – for example, if transit or bike paths are unavailable more people may drive private vehicles, increasing overall emissions – as well as a shift in where vehicles travel. If traffic shifts from exposed routes to inland roads, there could be local increases in air and water pollution in those neighborhoods.

<u>Governance</u>
The governance structures related to transportation projects and assets are sensitive to climate impacts transportation planning requires significant interagency involvement at all levels of

[7] http://www.actransit.org/about-us/facts-and-figures/ridership/

government (funding agencies, operating agencies, regulatory, agencies, land owners and land managers, etc.).

AC Transit, for example, receives funding from a broad mix of federal, state, and local government subsidies, as well as voter-approved funding initiatives. Over the past decade, voters in the Alameda-Contra Costa Transit District approved two special parcel tax measures (Measure BB and Measure VV) to provide additional temporary funding to AC Transit. Measure VV extended the funding initially provided through Measure BB until June 30, 2019, but such funding is clearly vulnerable to voter shifts and political change.

Currently, a significant improvement project is being undertaken by Caltrans to rehabilitate many aging sections of Interstate 880. One of the most important undertakings is the 5th Avenue Seismic Retrofit Project, a $130 million project developed through a partnership with the City of Oakland, the Port of Oakland, Union Pacific Railroad, and the Alameda County Transportation Commission. Construction began in summer 2009 and is scheduled to be complete in spring 2014. While the investment to improve this section of road is significant, this project will not reduce the area's vulnerability to inundation. In other words, while efforts were made to pool funds from a variety of governing agencies for this transportation project, future sea level rise may nevertheless affect long-term operations and maintenance costs.

Key Findings

Ground transportation in the ART project area consists of a system of roadways, interstates, Bay Area Rapid Transit, rail lines, bus routes, ferry routes and bicycle and pedestrian pathways. The system includes both physical assets such as rail stations, bus stops, ferry terminals, rail and road infrastructure, and the functional role of linking people with community facilities and services, jobs, family and friends, recreation, and other important destinations. The ground transportation system has components that are projected to be exposed to earlier sea level rise scenarios; while only a few are exposed to the daily high tide with 16 inches of sea level rise, a number of important assets become exposed with 16 inches of sea level rise and a storm event. Ground transportation is quite sensitive to sea level rise and storm events, as many of the systems cannot operate when exposed to even small amounts of water. The overall system has medium to high adaptive capacity, as there is a lot of redundancy in the region's ground transportation system. However, certain components of the system-such as rail serving cargo and the shoreline bicycle and pedestrian pathways–do not have much redundancy.

The ground transportation assets that are exposed earliest – to either the daily high tide or storm events with 16 inches of sea level rise – include the Webster and Posey Tubes that link the City of Alameda and the City of Oakland; portions of Interstate 80/580 and Interstate 880; the approaches to the Bay Bridge, the roadways to Oakland International Airport; the passenger and cargo rail lines, the Bay Trail; and a number of local streets and roadways near the shoreline that provide access to shoreline communities, parks, the Bay Trail, and ferry terminals. With 55 inches of sea level rise, the number of ground transportation assets exposed to the daily high tide and storm events increases significantly.

The majority of the BART system within the subregion does not appear to be exposed to the daily high tide or storm events with 16 inches of sea level rise. Even with 55 inches of sea level rise, BART does not appear to have significant exposure to and the daily high tide or storm events. Many of BART's assets are elevated, which eliminates the possibility of exposure to those parts of the BART system. However, a number of BART's assets are also underground, including rail, the Transbay Tube that links the City of San Francisco with the City of Oakland, and important electrical components. Although BART does not appear to be exposed to most of the daily high tide and storm scenarios, it may be exposed to rising groundwater. Additionally, BART's underground assets and electrical components are highly sensitive to even small amounts of water and the consequences of exposure of these assets can mean that the entire BART system or a significant portion of the system will be shut down. The presence of the Transbay Tube within the subregion, and its critical role as the only location where BART crosses the Bay, makes this a particularly sensitive asset. The consequences to the economy, society, and environment of any BART shutdown in this area are significant even though there is redundancy in the ground transportation system. A partial or system-wide BART closure results in more people driving, more emissions and associated air and water quality issues, more congestion, and an increased number of riders on other modes of transportation. The vulnerability of the BART system is **acute,** due to the high consequences of disruption to the system.

The system of ferry routes and terminals does not appear to be exposed to the daily high tide or storm events with 16 inches of sea level rise. Additionally, much of the infrastructure for ferry terminals is adaptive to water exposure and increased water levels. The primary exposure for the ferry system is the exposure of the roadways, parking, and pedestrian and bicycle pathways that serve the ferry terminals. Without the ability to access the ferry terminals, passengers would be unable to use the service even if the terminals were not affected. It is also important to note that ferry operations are extremely sensitive to storm events and with a certain amount of wind and waves, must be shut down. The consequences of delayed or temporarily unavailable service in Oakland and Alameda would be displaced riders, increased congestion on the roadways and effects on air and water quality. The vulnerability of the ferry system is low to medium due to its lack of exposure and the redundancy of other forms of transportation that are available.

The Bay Trail is exposed to the daily high tide and storm events with 16 inches of sea level rise, and would be significantly affected by the daily high tide and storm events with 55 inches of sea level rise. Due to the nature of its construction and its location within the subregion, the Bay Trail is highly sensitive to sea level rise and flooding affects. Erosion, poor drainage, and surface damage can all result in the closure or elimination of a portion of the Bay Trail. Due to the importance of the Bay Trail as a system of interlinked pathways, the consequence of closing or eliminating a portion of the Bay Trail can be significant. Although there are adaptive measures that can be taken such as different types of construction and construction materials, improved drainage, and the design of boardwalks and bridges, at a certain level of exposure, many of these adaptive measures could be overwhelmed. The vulnerability of the Bay Trail is high due to its exposure to early sea level rise and storm events, its sensitivity to water exposure and the fact that adaptive measures may be overwhelmed in some cases. The consequences of this vulnerability for society, economy, and environment will depend upon the location of the closure or elimination. It may result in reduced access opportunities for people with disabilities or reduced mobility, and could result in more people driving rather than walking or bicycling to their destinations. The lack of redundancy results in an acute vulnerability.

The passenger and cargo rail infrastructure is exposed to the daily high tide and storm events with 16 inches of sea level rise. Rail infrastructure is highly sensitive to even small amounts of water and if a portion of a rail line is exposed it often results in the closure of many miles of tracks. The rail lines within the subregion do not have redundant, adjacent, or alternative tracks to use in the case of a closure, reducing the adaptive capacity of the rail system. The planning, financing and implementation of additional or rehabilitated rail infrastructure would take a significant amount of time and money as it is difficult to move rail either laterally or vertically without making changes to many miles of track.

The consequences of the effects on the passenger rail system would be an increase in the number of people driving, decreased transit opportunities for those without access to a car, and the displacement of rail passengers to other forms of transit. The consequences of the effects on the cargo rail system would be an increase in the number of trucks needed to transport cargo, with associated local and regional effects on congestion, air quality, and community noise and quality of life. The vulnerability of the passenger and cargo rail system is high due to its exposure to the daily high tide and storm events with 16 inches of sea level rise.

The bus routes in the subregion use local roads, highways, and interstates, some of which are likely to be exposed to the daily high tide and storm events with 16 inches of sea level rise. Bus routes and bus stops may be sensitive to these impacts and unable to operate at a certain level of inundation. However, bus routes and bus stops are mostly highly adaptive and can be rerouted to adjacent roadways quite easily. The society and equity consequences of rerouting a bus route or relocating a bus stop could be locally significant and should be considered on a case–by-case basis. Due to their adaptive nature, buses and bus routes will likely serve a significant short-term and long-term role in regional adaptation. The vulnerability of bus routes and bus stops is low due to the high adaptive capacity of most of the bus system.

References

Adapting to Rising Tides (ART). 2011. Adapting to Rising Tides Transportation Vulnerability Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project. November 2011. Prepared by AECOM and Arcadis for the San Francisco Bay Conservation and Development Commission, Metropolitan Transportation Commission and the California Department of Transportation. Available at http://www.mtc.ca.gov/news/current_topics/10-11/sea_level_rise.htm.

AC Transit. 2008. GM Memo No. 08-033, Annual Route Performance Review: 2007. http://transbay.files.wordpress.com/2008/02/ac_performance_2007.pdf.

Alameda Patch. 2012. BART to Bolt Heavy Steel Plates inside Tube. http://alameda.patch.com/articles/bart-to-bolt-heavy-steel-plates-inside-tube-1bead32f.

Amtrak. 2011. News Release, October 13, 2011. Amtrak Ridership Rolls up Best-Ever Records. http://www.amtrak.com/servlet/BlobServer?blobcol=urldata&blobtable=MungoBlobs&blobkey=id&blobwhere=1249232964000&blobheader=application%2Fpdf&blobheadername1=Content-disposition&blobheadervalue1=attachment;filename=Amtrak_ATK-11-133_Record_FY11_Ridership_and_Revenue.pdf.

Heberger, M., H. Cooley, P. Herrera, P.H. Gleick, and E. Moore. 2009. The Impacts of Sea level Rise on the California Coast. Pacific Institute.

Metropolitan Transportation Commission (MTC). 2011. Daily Clipper Card Use Tops the Half-Million Mark. http://www.mtc.ca.gov/news/current_topics/9-11/clipper.htm.

Metropolitan Transportation Commission (MTC). 2009. Transportation 2035 Plan, Equity Analysis Report. http://www.mtc.ca.gov/planning/2035_plan/equity.htm.

Chapter 12. Wastewater Facilities

Wastewater, or sewage, is the refuse liquid and waste materials from washing, flushing or industrial processes. Wastewater is collected, conveyed, treated, and discharged through an interconnected network of structures and facilities. Although these wastewater assets may be owned and operated by separate providers, they function together to provide critical services to the communities they serve while protecting Bay water quality and natural resources.

Wastewater collection assets are those facilities that protect public health by conveying wastewater from its source to treatment and discharge facilities. These include privately owned sewer laterals that connect individual properties to the public system, and publically owned sewer mains, force mains, and interceptor pipelines. Additionally, there are pump stations that lift wastewater throughout the collection system as it travels to the treatment plant, and from the treatment plant to the ultimate discharge location. The assessment of wastewater collection assets is limited to pump stations owned or operated by two cities and four special districts in the ART project area that lift wastewater in interceptor sewer pipelines. This subset of pump/lift stations in the ART project area was included because there was sufficient data and information to evaluate them, they are generally representative of pump/lift stations, and they are all owned and/or operated by wastewater treatment and discharge providers (Table 1). Public sewer pipelines, including mains, force mains and interceptors, and private sewer laterals, are not evaluated in detail, but are considered in the discussion of potential vulnerability and risk to the function of the overall wastewater system.

Wastewater treatment assets are the facilities that treat wastewater prior to discharge. These include wastewater treatment plants (WWTP) and satellite facilities that store and manage flows during wet weather events (wet weather facilities). Of the seven WWTP in Alameda County, five are located within the ART project area (Table 1). These WWTP have a range of design capacities (20 to 120 million gallons per day), service areas (8.5 to 88 square miles), and service connections (18,500 to 178,400).

Wastewater discharge assets are comprised of the facilities that disinfect and dechlorinate treated wastewater and discharge it to the Bay. There are two primary discharge facilities in the ART project area. The East Bay Municipal Utility District (EBMUD) discharges treated sewage from a population of more than 650,000 to a submerged diffuser more than a mile offshore at a depth of 45 feet adjacent to the San Francisco-Oakland Bay Bridge. The East Bay Dischargers Authority (EBDA) discharges treated sewage via a 7-mile long outfall pipeline near the San Leandro Marina from a population of almost 800,000 in the communities served by its member agencies (the Cities of San Leandro and Hayward, Union Sanitary District, Oro Loma Sanitary District, and Castro Valley Sanitary District) and the Livermore-Amador Valley Water Management Agency (LAVWMA).

In addition to the primary discharge assets described above, in the ART project area EBMUD owns and operates a dechlorination facility associated with the San Antonio Creek wet weather facility and four overflow structures spread throughout the interceptor pipeline system. In addition, some of the treatment plants in the ART project area have access to emergency discharge locations to prevent overflows and backups when flows exceed system capacity. These structures were not evaluated separately as they are generally located within the treatment plant footprint.

Table 1. Summary of wastewater facilities and service providers in the ART project area.

System	**Owner/ operator**	**Main facility**	**Design capacity** (MGD)	**Average annual flow** (2010 MGD)	**Peak wet weather flow** (MGD)	**Population served / Service area**	**Pump stations (**in project area {total})	**Other facilities and assets**
EBMUD	**East Bay Municipal Utility District**	Main Wastewater Treatment Plant	120	70	320	650,000 88 sq. mi.	12 {15}	Three wet weather facilities (two in project area), two dechlorination facilities, discharge transition structure, four overflow structures
EBDA*	**East Bay Dischargers Authority***	EBDA Common Outfall	107.8	72.3	189.1	800,000	4 {5}*	Dechlorination facility
	City of Hayward	Hayward Water Pollution Control Facility	18.5	12.2	35	153,000 62 sq. mi.	{9}	Sludge drying beds, out-of-service oxidation pond
	City of San Leandro	San Leandro Water Pollution Control Plant	33	4.9	22.3	55,000 8.5 sq. mi.	7 {13}	Sludge drying beds, out-of-service oxidation pond
	Oro Loma Sanitary District^	Oro Loma Wastewater Treatment Plant	20	12.6	69.2	182,000 13 sq. mi.	3 {14}	Sludge drying beds
	Union Sanitary District	Alvarado Wastewater Treatment Plant	33	25.1	42.9	337,560 60 sq. mi.	{7}	Emergency wet weather outfall+, Hayward marsh discharge facility++

* EBDA conveys and discharges wastewater from communities served by its five member agencies and LAVWMA, including San Leandro, Hayward, Union City, Newark, Fremont, Pleasanton, Dublin, and Livermore; **The EBDA pump stations are operated by the member agencies

^ The Oro Loma Wastewater Treatment Plant is owned jointly by the Oro Loma and Castro Valley Sanitary Districts, but is operated by the Oro Loma Sanitary District

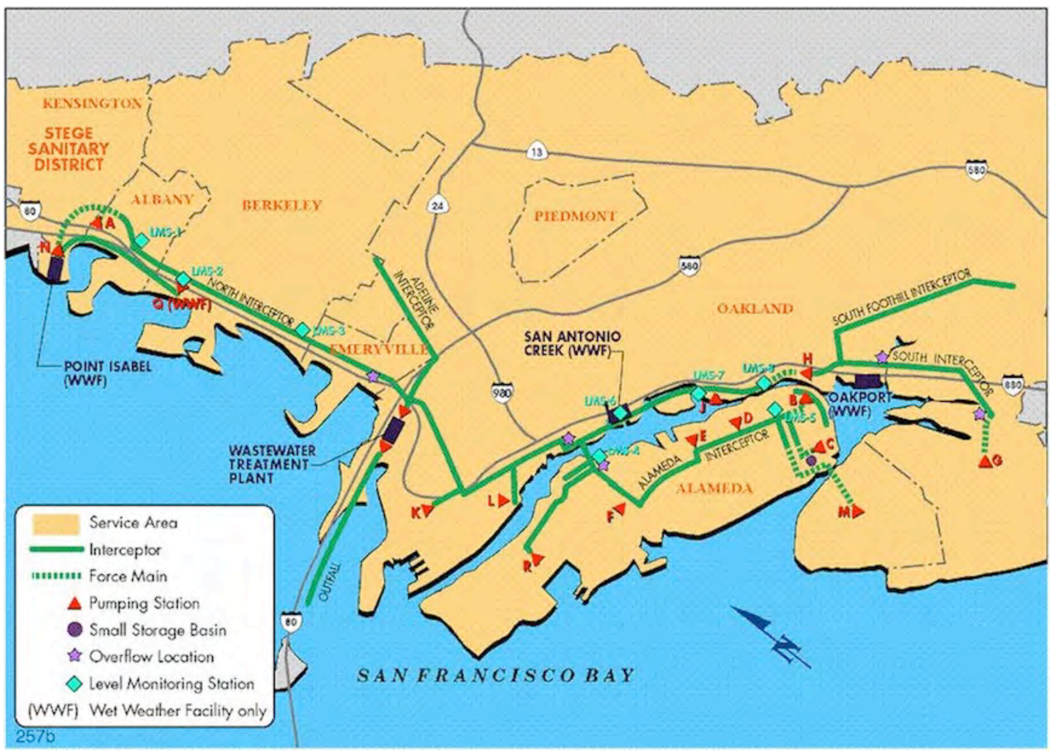
+Located within the footprint of the treatment plant, not evaluated separately

++Not evaluated

East Bay Municipal Utility District (EBMUD) serves an 88-square mile area with a population of more than 650,000 individuals. Residential, commercial, and industrial wastewater services are provided to seven East Bay communities, including Alameda, Albany, Berkeley, Emeryville, Oakland, Piedmont and the Stege Sanitary District[1] (Figure 1). City-owned collection systems discharge wastewater from these communities (three of these – Alameda, Emeryville and Oakland – are wholly or partially within the ART project area) to EBMUD's interceptor system, which conveys it to the main wastewater treatment plant, located in Oakland. In addition to the main WWTP, EBMUD owns and operates three wet weather facilities, 15 pumping stations, 29 miles of intercepting sewers, 8 miles of sewer force mains, and four overflow structures.

The EBMUD wastewater system is already subjected to high flows during wet weather due to infiltration and inflow (I/I). Throughout the service area, private sewer laterals and community collection systems are in varying condition; where sewer pipes are deteriorating, stormwater and groundwater infiltrates into the collection system (infiltration), and where there are improper connections, stormwater can flow into the system (inflow). Excess flows during wet weather can result in a sanitary sewer overflow or the activation of wet weather facilities.

Figure 1. EBMUD service area and assets (Source: EBMUD).

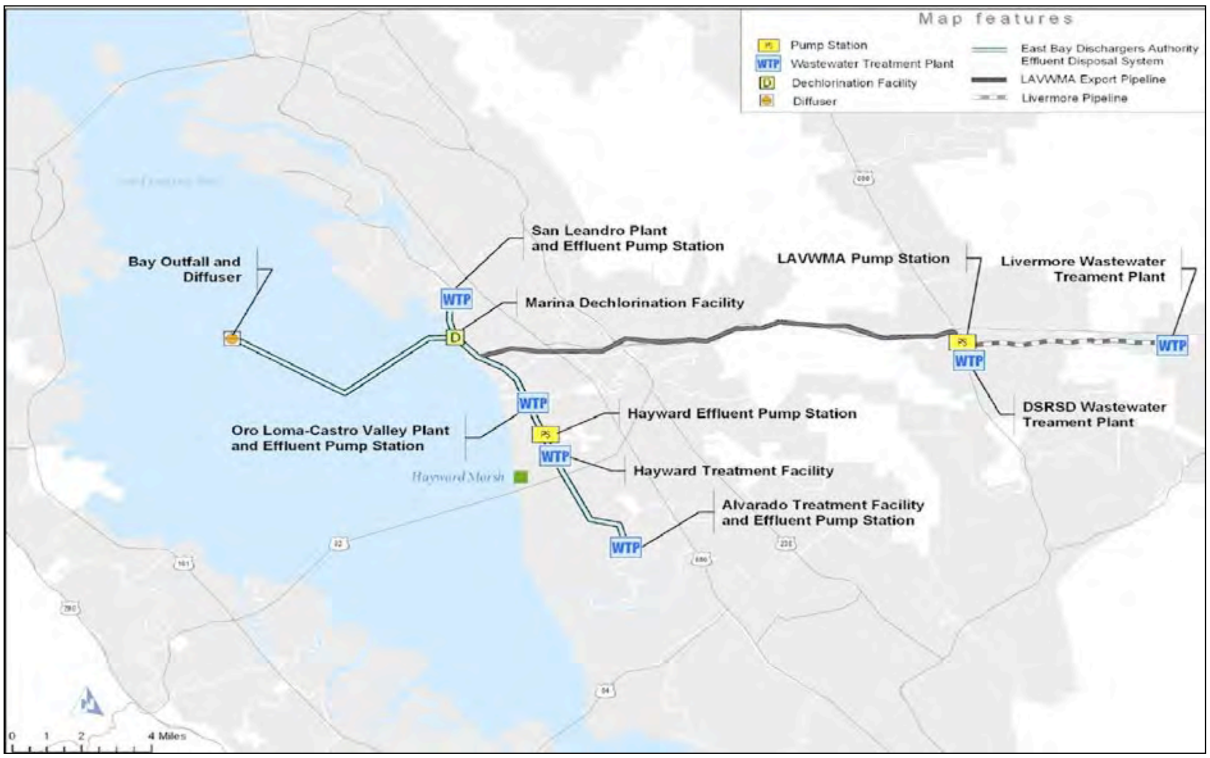


East Bay Dischargers Authority (EBDA) is a Joint Powers Authority (JPA) with five member agencies: the cities of San Leandro and Hayward, Union Sanitary District (USD), Oro Loma Sanitary District (OLSD) and Castro Valley Sanitary District (CVSD). EBDA handles wastewater from a population of approximately 800,000 individuals served by the member agencies and the

[1] The Stege Sanitary District is an independent Special District that provides sanitary sewer services to Kensington, El Cerrito and a portion of Richmond known as the Richmond Annex.

Livermore-Amador Valley Water Management Agency[2] (LAVWMA). Wastewater discharged through the EBDA system comes from the communities of San Leandro, Hayward, Union City, Newark, Fremont, Pleasanton, Dublin, and Livermore. City or district owned collection systems convey the wastewater to one of the six WWTP in the EBDA service area (Figure 2, Note: the Livermore and the DSRSD WWTPs are not in the ART project area). Treated wastewater from the WWTPs is then conveyed though a disposal system comprised of pipes and pumps to the EBDA Marina Dechlorination Facility, where residual chlorine is removed to reduce toxicity prior to being discharged via the EBDA Joint Outfall[3].

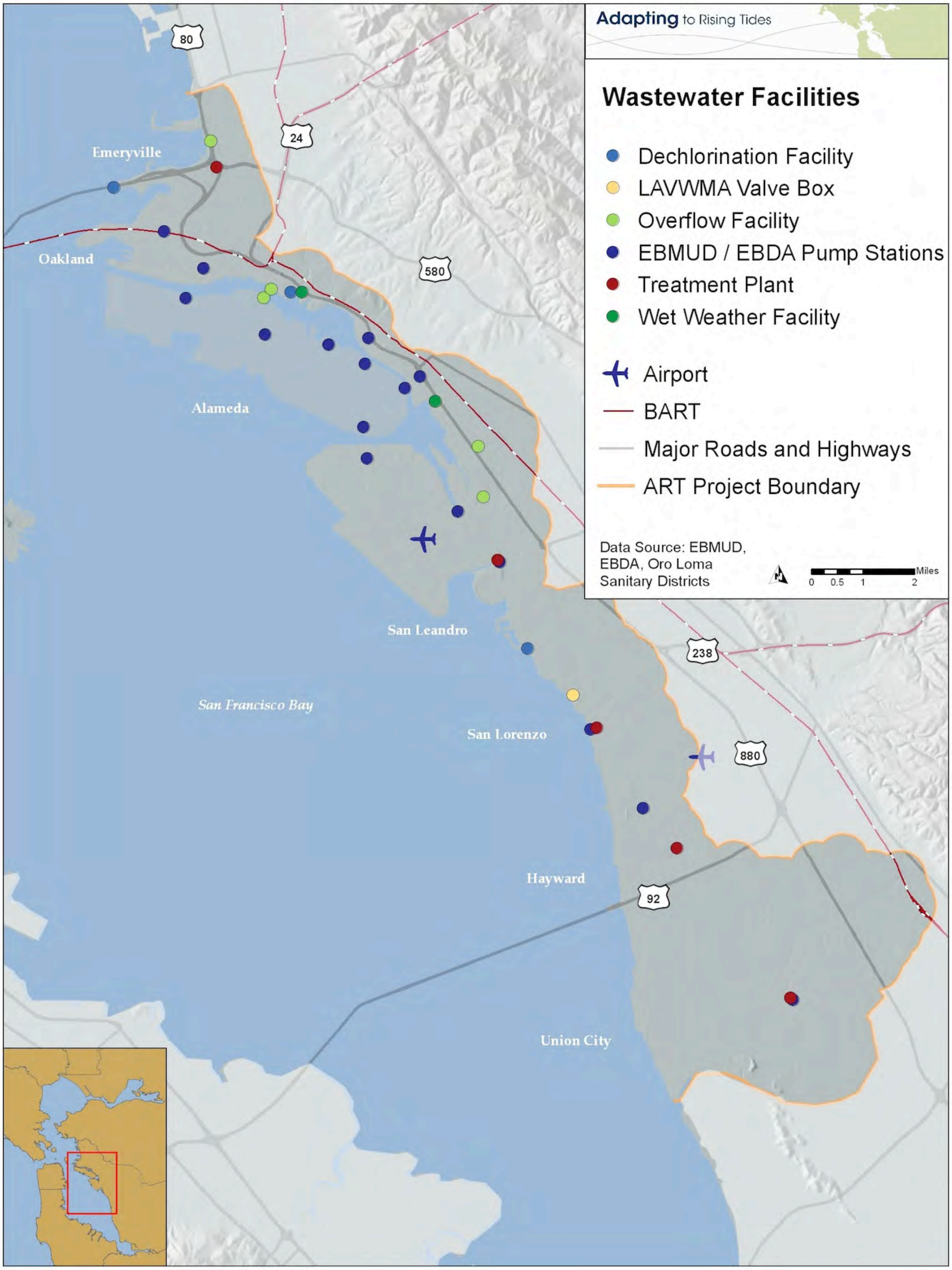
Figure 2. EBDA service area, disposal system, dechlorination facility and outfall location, and contributing wastewater treatment plants (Source: EBDA)



Conveyance through the EBDA disposal system is driven by a series of pump stations. EBDA owns five of these pump stations, each which is operated by a different member agency or LAVWMA. Importantly, three pump stations are responsible for driving the flow of wastewater to the EBDA Joint Outfall. Two of these are located in the ART project area at OLSD and San Leandro WWTPs, and one outside the project area (a LAVWMA pump in Dublin).

[2] The Livermore-Amador Valley Water Management Agency (LAVWMA) is a joint powers agency created in 1974 by the cities of Livermore and Pleasanton and the Dublin San Ramon Services District for the purpose of discharging their treated wastewater to San Francisco Bay.
[3] The EBDA outfall pipeline is approximately seven miles long, with the last 2,000 feet a diffuser section designed to ensure maximum dilution and mixing with deep Bay waters.

Figure 3. Wastewater facility locations within the ART project area.



Exposure

Exposure is the extent to which an asset, in this case a wastewater facility, experiences a specific climate impact such as storm event flooding, tidal inundation, or elevated groundwater. The exposure of wastewater assets in the ART project area (Figure 3) was evaluated for to two sea level rise projections and three Bay water levels. The two sea level rise projections, 16 inches (40 cm) and 55 inches (140 cm), correlate approximately to mid- and end-of-century. These two sea level rise projections were coupled with three Bay water levels: the highest average daily high tide represented by mean higher high water (MHHW), hereafter "high tide" or "daily high tide"; the 100-year extreme water level, also known as the 100-year stillwater elevation (100-year SWEL), hereafter "100-year storm" or "storm event"; and the 100-year extreme water level coupled with wind-driven waves, hereafter "storm event with wind waves", or "wind waves." These water levels were selected because they represent a reasonable range of potential Bay conditions that will affect flooding and inundation along the shoreline. For more information about sea level rise projections and Bay water levels evaluated see Chapters 1 and 2.

Exposure was evaluated using two different approaches (see Appendix C). For the larger wastewater assets such as treatment plants, ancillary facilities, and wet weather facilities, the extent of the facility footprint exposed to each sea level rise projection and Bay water level was determined. Facility footprints were identified using aerial imagery in combination with the Alameda County Assessor parcel information, and are therefore an approximation rather than an exact facility boundary. For the smaller wastewater assets such as pump stations, dechlorination facilities, and overflow structures, exposure was determined within a circular 164-foot (50-meter) diameter footprint centered on the point location of the facility. This approach was verified as being representative of the approximate footprint of most of the smaller assets evaluated.

For the larger assets, the percent of the facility footprint exposed and the average depth within the area of exposure was calculated for the daily high tide and storm event scenarios. For the smaller assets the average depth of inundation was determined for the entire facility footprint for the daily high tide and storm event scenarios. Whether the asset was exposed to wind waves only, or was within a disconnected low-lying area[4], was also evaluated in a binary, i.e., yes versus no, analysis.

Figure 4. EBMUD's pump station G.

16 inches of Sea Level Rise

With 16 inches of sea level rise, only one wastewater asset, EBMUD's pump station G, is exposed to the daily high tide (Figure 4). This pump station is located on Doolittle Drive near the Oakland International Airport and is potentially exposed to 4 feet of inundation.

Seven wastewater assets are located in disconnected low-lying areas adjacent to land potentially inundated by the daily high tide with 16 inches of sea level rise. These include

[4] Disconnected Low-lying areas are at the same elevation or are lower than an adjacent inundated area. Assets in these areas are not considered exposed because a topographic feature such as a railroad or road embankment should prevent inundation. However, they could be exposed if the protective feature fails. See Chapter 2 for a more detailed explanation.

EBMUD's Elmhurst Creek overflow structure and Oakport wet weather facility; Hayward's sludge drying beds and out-of-service oxidation ponds; OLSD's treatment plant; and San Leandro's out-of-service oxidation ponds and Neptune lift station located on Monarch Bay Drive. While not directly exposed, these assets have a potential risk of flooding depending on the type or condition of the topographic feature that is shown to protect them from inundation or flooding. In addition, access to facilities located in low-lying areas could be limited if and when adjacent areas are inundated.

Three treatment plants are exposed to 2 feet of storm flooding with 16 inches of sea level rise, including OLSD, San Leandro, and USD. Hayward's sludge drying beds and out-of-service oxidation ponds are exposed to 6 feet of flooding, EBMUD's discharge transition structure to 2 feet, and a portion of OLSD's sludge drying beds to 3 feet (Table 2). Three EBDA, three EBMUD, and one San Leandro pump station are exposed to 1 to 2 feet of flooding, while EBMUD's pump station G is exposed to 6 feet (Table 3).

During storm events there can be wind-driven waves that can lead to overtopping and erosion of the shoreline and shore protection infrastructure. All of the assets exposed to storm event flooding would also be exposed to wind waves, which would likely increase flood depths beyond those presented in Tables 2 and 3. In addition, there are a number of facilities exposed only to wind waves only during a storm event. Areas exposed to wind waves only could potentially experience shallow flood depths for short durations. Wind-driven waves can elevate Bay water levels significantly, but as the wind waves travel inland they tend to dissipate and flood depths will decrease. Because overland wave propagation and dissipation processes was not evaluated the additional depth of inundation due to wind waves was not determined. With 16 inches of sea level rise, two WWTPs, two dechlorination facilities, two overflow structures, one wet weather facility, and sixteen pump stations are exposed to wind waves only (Tables 2 and 3).

55 inches of Sea Level Rise

With 55 inches of sea level rise, more than half of the wastewater assets evaluated (24 of 45) are potentially exposed to the daily high tide. More than 80% of the OLSD, San Leandro and USD WWTP footprints are exposed to 2 to 3 feet of inundation, and approximately one-quarter of EBMUD's Main WWTP footprint is exposed to 1 foot of inundation. Only the Hayward WWTP is not exposed to tidal inundation with 55 inches of sea level rise. Additionally, the oxidation ponds and sludge drying beds, the EBMUD Transition Structure, the Alameda Estuary and Elmhurst Creek overflow structures, and the San Antonio wet weather facility and dechlorination structure are exposed (Table 2).

With 55 inches of sea level rise, 13 of the 27 pump stations evaluated are exposed to 1 to 7 feet of inundation from the daily high tide. This includes EBDA's Alvarado, Hayward, San Leandro, and LAVWMA Valve Box effluent pump stations; EBMUD's pump stations C, F, G, L, M, and R; and San Leandro's Bermuda, Neptune, and Wick's lift stations. The three OLSD pump stations evaluated are not exposed, nor was EBDA's Oro Loma effluent pump station, which is critical to the overall function of the EBDA disposal system (Table 3).

Three facilities are located in a low-lying area adjacent to the land potentially inundated by the daily high tide with 55 inches of sea level rise. These include EBMUD's Oakport wet weather facility, Hayward's WWTP, and San Leandro's Marina Park lift station. While not directly exposed, these assets have a potential risk of flooding depending on the type or condition of the topographic feature that is shown to protect them from direct exposure.

All of the treatment plants, ancillary, discharge, and wet weather facilities are exposed to storm flooding with 55 inches of sea level rise. In some cases, only a portion of the facility is exposed (e.g., 25% of the footprint), while in others the entire facility is exposed. The depth of flooding ranges from 1 to 9 feet, with the deepest inundation in the out-of-service oxidation ponds and the shallowest at EBMUD and Hayward's WWTPs, the EBDA dechlorination facility (Figure 5), and EBMUD's San Leandro Creek overflow structure (Table 2).

A total of 13 pump stations are exposed to storm flooding with 55 inches of sea level rise, including four EBDA, six EBMUD, and three San Leandro pump stations. Most of these pump stations are exposed to 1 to 4 feet of storm flooding, however, EBMUD's pump station G is exposed to 7 feet of flooding (Table 3). The remaining 14 pump stations are exposed to wind waves only (Table 3).

Figure 5. EBDA's Marina Dechlorination Facility.

Table 2. Exposure of treatment plants, ancillary, discharge, and wet weather facilities to storm event flooding and wind waves with 16 and 55 inches of sea level rise. Depth of inundation and percent of facility footprint exposed is provided where evaluated. All facilities exposed to storm flooding are within the wind wave zone, and could experience deeper inundation than presented because Bay water surface levels increase when there are wind waves. All facilities are exposed to storm event flooding with 55 inches of sea level rise, therefore no facilities are exposed to wind waves only.

Asset	16" SLR			55 "SLR			
	Storm Event			Daily High Tide		Storm Event	
	% Exposed	Average depth (ft)	Exposed to wind waves only	% Exposed	Average depth (ft)	% Exposed	Average depth (ft)
Treatment Plants							
EBMUD Main WWTP			Yes	26	1	83	2
Hayward			Yes			25	2
OLSD	69	2		81	3	100	4
San Leandro	82	2		90	2	96	5
USD Alvarado	98	2		99	3	100	6
Ancillary Facilities							
Hayward Oxidation Ponds	92	6		94	7	100	9
San Leandro Pond & Drying Beds			Yes	41	8	46	9
OLSD Sludge Drying Beds	23	3		72	3	72	3
Dechlorination and Discharge Facilities							
EBDA Dechlor Facility*			Yes			-	1
EBMUD Dechlor Facility			Yes			100	2
EBMUD Transition Structure	80	2		80	3	80	6
EBMUD San Antonio Creek (Dechlor Facility)*	-	1		-	2	-	4
EBMUD Alameda Estuary Overflow Structure*	-	2		-	2	-	5
EBMUD Elmhurst Creek Overflow Structure*	-	3		-	4	-	6
EBMUD Oakland Estuary Overflow Structure*			Yes			-	3
EBMUD San Leandro Creek Overflow Structure*			Yes			-	1
Wet Weather Facilities							
EBMUD Oakport			Yes			98	5
EBMUD San Antonio Creek	3	1		63	1	100	3

* Percent of facility exposed was not calculated for these structures due to their small size

Table 3. Exposure of pump stations to storm event flooding and wind waves with 16 and 55 inches of sea level rise. Only depth of inundation is provided since percent of facility exposed was not calculated for these structures due to their small size. All facilities exposed to storm flooding are also within the wind wave zone, and could experience deeper inundation than presented because Bay water surface levels increases when there are wind waves.

Asset	16" SLR		55 "SLR		
	Storm Event		Daily High Tide	Storm Event	
	Average depth (ft)	Exposed to wind waves only	Average depth (ft)	Average depth (ft)	Exposed to wind waves only
EBDA Pump Stations					
Alvarado EPS	2		3	3	
Hayward EPS		Yes	1	1	
LAVWMA Valve Box	1		2	2	
Oro Loma EPS		Yes			Yes
San Leandro EPS	2		3	3	
EBMUD					
Pump Station B		Yes			Yes
Pump Station C	1		1	1	
Pump Station D		Yes			Yes
Pump Station E		Yes			Yes
Pump Station F		Yes	1	1	
Pump Station G	6		7	7	
Pump Station H					Yes
Pump Station J					Yes
Pump Station K		Yes			Yes
Pump Station L		Yes	1	1	
Pump Station M	1		2	2	
Pump Station R		Yes	1	1	
OLSD					
Lift Station 1-Trojan		Yes			Yes
Lift Station 2-Bockman		Yes			Yes
Lift Station 4-Railroad					Yes
San Leandro					
Bermuda L/S	2		3	3	
Blue Dolphin L/S		Yes			Yes
Catalina L/S		Yes			Yes
Marina Park L/S		Yes			Yes
Merced L/S					Yes
Neptune L/S		Yes	4	4	
Wicks Extension L/S		Yes	1	1	

Sensitivity and Adaptive Capacity

The sensitivity and adaptive capacity of wastewater facilities in the ART project area was assessed for three potential climate impacts that could occur due to sea level rise and storm events. The three climate impacts considered are:

- More frequent flood or floods that last longer due to storm events
- Permanent or frequent inundation by the daily high tide
- Elevated groundwater levels and saltwater intrusion

Sensitivity is the degree to which a wastewater asset or system would be physically or functionally impaired if exposed to a climate impact. In the following assessment the sensitivity of wastewater assets to storm event flooding, tidal inundation, and elevated groundwater levels is assessed. Adaptive capacity is the ability for a wastewater asset or system to accommodate or adjust to a climate impact and maintain or quickly resume its primary function. The capacity to accommodate or adjust to storm event flooding or elevated groundwater levels is considered for the individual assets and for the system as a whole (as described above).

Each specific type of wastewater asset in the ART project area such as treatment plants, pump stations, and dechlorination facilities, is first assessed separately. Then, the sensitivity and adaptive capacity are considered for each of the wastewater service areas in the ART project area – the EBMUD service area in the northern portion of the project area and the EBDA service area in the southern portion.

Specific Wastewater Assets

Wastewater treatment plants (WWTPs)
There are five WWTPs in the ART project area, each with unique features and operational considerations (see Table 1). There are, however, similarities in the physical and functional properties of these WWTPs that inform an understanding of the sensitivity and adaptive capacity of these facilities as a whole.

In general, the primary function of a WWTP – treating wastewater in order meet water quality discharge requirements – is highly sensitive to storm events and tidal inundation. Flooding could increase flows at a WWTP beyond capacity, resulting in operational failures, overflows, and backups. Additionally, there are many individual units or facilities that comprise a WWTP. While some may be constructed to operate in moist or submerged conditions, others are not. Most facilities have significant underground components that are key to their continued operation that are highly susceptible to even low levels of flooding. Equipment with electrical components such as motors, instrumentation, and motor control centers is particularly sensitive to storm events or tidal inundation, and would cease to operate if they were to get wet.

WWTPs as a whole, and the individual facilities or units that comprise them, have varying degrees of adaptive capacity. In general, WWTPs have a moderate ability to accommodate or adjust to infrequent, short duration flooding, but a very low capacity to cope with more frequent, or longer duration inundation. For example, during small or relatively brief flood sandbagging and onsite pumping could reduce events adverse impacts. If the impact of small, brief storm events is mitigated, then facilities may either remain fully functional or be restored to full function in a matter of days, although the potential consequences of even a short duration disruption in service could be significant. Additionally, WWTPs rely on a power supply that may be interrupted by a storm event or tidal inundation. While backup power is available from portable or on-site generators, these units require fuel resupply to operate beyond a short period.

For longer duration or larger storm events, avoiding or accommodating adverse affects would be challenging as the amount of flooding would likely overwhelm temporary measures to protect the facilities, and the effort to recover from such events would be considerable. As discussed above, key equipment (such as electrical components) can be sensitive to even small amounts of flooding, and the ability to keep this equipment dry and operational, for example through portable pumping or sand bagging, during a storm event would be challenging. Storm events that result in failure or inoperability of wastewater facilities would require significant time and resources to complete repairs and re-instate functionality.

Lastly, due to the size, complexity, and the capital investment required to build, own and operate a WWTP, there is no duplication or redundancy in wastewater treatment in any given service area. If a WWTP is compromised, the service it provides will be interrupted, as generally there are no good alternative means to replace that function. There is, however, some redundancy in component units within each WWTP, although generally all of the units are required to be operational to provide full treatment capacity. Depending on the part of the WWTP affected and the duration of flooding, having duplication or redundancy in some components could allow the WWTP to continue to function, albeit at reduced capacity. For example, the City of Hayward's water pollution control facility has three primary clarifiers, two final clarifiers, and three digesters. These redundant components provide the plant with some capacity to accommodate or adjust to the impacts of sea level rise or storm events. There are, however, some component units that have no redundancy. For example, the Hayward plant has one vacuator, one gravity belt thickener, and one standby emergency power generator. These units have high capital replacement costs and cannot be easily reengineered or redesigned.

WWTP component units are generally not directly sensitive to increases in groundwater levels or saltwater intrusion. Additionally, they either already have the adaptive capacity or can easily acquire the adaptive capacity to respond to these potential impacts. WWTPs may, however, be indirectly sensitive to rising groundwater as there may be limited capacity to accommodate increased flows from additional infiltration into the collection system. The sensitivity and adaptive capacity of wastewater systems as a whole, including the collection system components, is considered in greater detail below.

Wet weather facilities

The two wet weather facilities in the ART project area are sensitive to storm event flooding and tidal inundation, but not to elevated groundwater or salt water intrusion. These facilities provide storage during wet weather to reduce excess flows and avoid sewer system overflows due to infiltration and inflow (I/I)[5]. The wet weather facilities in the ART project area are owned and operated by EBMUD. Both facilities are tanks built into the ground that are not enclosed or protected from storm flooding or tidal inundation. These facilities may remain operable if flooding is minimal or short-term, but they would not be able to maintain their primary function (storage) if fully flooded or inundated.

The wet weather facilities have low adaptive capacity. There are no comparable alternative assets that could function in their place if they were compromised (i.e., no redundancy). They have moderate to high O&M costs, and therefore it may be difficult to restore their function with minimal intervention once flood flows have receded, although this will depend on the extent of the impact. Lastly, they have high capital replacement costs and are not the type of facility that could be easily redesigned or relocated.

[5] I/I is caused by deteriorating infrastructure that allows stormwater and groundwater to leak into the sanitary sewer system (Infiltration) or by improper connections that convey stormwater flows directly into the system (Inflow).

Out-of-service oxidation ponds
There is a complex of five out-of-service oxidation ponds at the Hayward water pollution control facility and one pond at the San Leandro water pollution control plant. These ponds no longer support the primary function of the WWTP. However, they can be used for emergency storage to avoid sanitary sewer overflows or the discharge of untreated or partially treated wastewater. The function of the ponds for emergency storage is sensitive to storm event flooding and tidal inundation, which would diminish their capacity to store flows from the WWTP. The ponds are also sensitive to higher groundwater levels if they are not fully lined with an impermeable barrier, or if the lining has ceased to be functional.

The oxidation ponds have moderate to low adaptive capacity because they have a limited ability to maintain their current primary function of storing excess flows during an emergency, especially if it were to co-occur with a storm event, tidal inundation, or high groundwater levels. In addition, neither Hayward nor San Leandro has a comparable alternative asset (i.e., no redundancy) that could provide emergency storage. If the ponds were disrupted or disabled, they are not easily redesigned or relocated, and the capital replacement cost would be high.

Sludge drying beds
Three of the WWTPs in the ART project area have sludge drying beds: Hayward, Oro Loma Sanitary District, and San Leandro. The beds are used to dry digested and dewatered sludge before it is transported off-site to an authorized disposal site. The primary function of the beds, to store and dry sludge, is sensitive to storm event flooding and tidal inundation. Additionally, the physical condition of the beds may be sensitive to erosion or degradation if exposed to storm flood flows or tidal inundation.

The sludge drying beds do have some adaptive capacity because, depending on the degree of impact (e.g., infrequent or short duration), they could be returned to function with either no or minimal intervention once the floods have receded. There are, however, no comparable designated alternative assets (i.e., no redundancy), although temporary sludge storage may be possible under emergency conditions. Finally, the beds are an outmoded design and new technologies or solutions would likely need to be used rather than redesigning or relocating them even though the cost to do so may be high.

Dechlorination and discharge facilities
There are three dechlorination facilities in the ART project area that serve to remove residual chlorine from secondarily-treated wastewater prior to discharge. Two are owned and operated by EBMUD. They comprise the main wastewater treatment plant dechlorination facility, which is co-located with the discharge transition structure and a facility that serves the San Antonio Creek wet weather facility. The third, the Marina Dechlorination Facility, is owned and operated by EBDA. These facilities are sensitive to storm event flooding and tidal inundation, but not necessarily to elevated groundwater levels. The facilities include chemical storage tanks (i.e., with sodium bisulfate), pumps, meters, and electrical and laboratory equipment that is used to control and monitor the dechlorination process. Storm event flooding or tidal inundation would compromise the electrical equipment and therefore disrupt the function of the facility. Additionally, these facilities rely on a supply of power to operate, and if back up power is either not available or able to operate for long enough, the facilities will not function.

The dechlorination facilities have low adaptive capacity, although it may be possible during small or relatively brief flood events to protect them with sandbags or onsite pumping. There is no alternative comparable replacement for these facilities, and they serve a critical function in protecting the ecology of the Bay by removing the residual chlorine prior to the discharge of treated wastewater. Additionally, they have fairly high O&M and capital replacement costs, and are not easy to redesign or relocate. Therefore, if adversely affected it is likely that they would not be easily or quickly returned to function without a significant resource investment.

Overflow structures

Five emergency overflow structures owned and operated by EBMUD were evaluated. While each WWTP has overflow structures that are operable in emergencies, the EBMUD structures are unique in that they are not located on the main treatment plant site; rather, they are in satellite locations along the EBMUD interceptor pipe system. These structures are not directly sensitive to storm events and tidal inundation as they are outfitted with duckbill check valves and do not rely on power or electronics to operate. They are, however, manually serviced and need to be accessible to maintenance staff. Additionally, the ability to overflow from these locations will depend on the tide level in the creek or estuary where they discharge as they rely on gravity rather than pumping. During extreme storm events or at high tide when creeks and channels are flooded it may not be appropriate nor possible to release flows from the interceptor system through these structures.

The emergency overflow structures have moderate to low adaptive capacity. While there is no comparable alternative to replace the individual overflow structures, there is some system-wide redundancy as there are five structures in total. Under certain conditions the structures may be able to provide relief to maintain the overall function of the interceptor system. Lastly, while the structures could be redesigned to accommodate the potential impacts, there are limited opportunities to relocate the structures, which need to discharge to a specific type of channel or waterway (e.g., a tidal creek or estuary).

Pump stations

A total of twenty-seven pump stations were evaluated, including 5 pump stations owned by EBDA and operated by its various member agencies, 12 EBMUD interceptor pump stations, and 3 OLSD and 7 San Leandro lift stations. Pump stations, which help convey wastewater, are sensitive to storm events and tidal inundation but not elevated groundwater levels. They have electrical equipment and computer instrumentation that are highly sensitive to flooding and exposure to salt water and rely on a power supply to operate. If the electrical equipment, computer controls, or power supply is compromised or disrupted, the pump station will not be capable of operating. Although some pump stations may tolerate small amounts of flooding without extensive physical damage, underground components that are not flood proofed or able to withstand moisture, or that have at-grade open components such as wet wells, will be susceptible to even low levels of flooding.

Even if not physically impaired, it is not likely that a flooded pump station could maintain functionality. The inflow of floodwaters into a pump station during a storm event or due to tidal inundation could also overload the pumping capacity, disrupting the conveyance of wastewater system-wide. As an example, treated chlorinated wastewater flows from the Hayward Treatment Plant to EBDA’s Hayward pump station in an open “final effluent channel.” While the pump station itself is not exposed to storm flooding with 16 inches of sea level rise, the channel would be, and the uncontrolled inflow of floodwaters into the channel could overwhelm this key EBDA pump station. The reliance on open channels, or open wet wells such as at EBDA’s Oro Loma pump station (Figure 6), will increase the sensitivity of these assets to sea level rise or storm event impacts.

In general, pump station adaptive capacity ranges from moderate to low depending on the size, location, and design of the facility. Smaller pump stations have greater adaptive capacity than larger ones because there is some capacity to maintain their function using portable pumps. Portable pumps could be used for short duration operational failures of small to moderate sized pump stations (e.g., design capacity of less than 10 million gallons per day (MGD)). Larger pump stations (e.g., EBMUD Pump Station H has a design capacity of 54 MGD) carry flows that are too large to be handled by portable pumps.

Figure 6. EBDA's Oro Loma effluent lift station. (Source: Google 2012)

Pump stations co-located with other wastewater assets, for example at the WWTP facility, have greater adaptive capacity than satellite pump stations. Not only will it be easier to access these pump stations both during and after a storm event, but there is a greater likelihood that they will be protected from flooding along with the rest of the treatment plant facilities and that there will be portable equipment, replacement parts, and manpower in close proximity.

Backup power supplies can mitigate disruption of the pump station if there is a power failure. However, backup power requires fuel resupply and may only be feasible for a short time period. Pump stations with no backup power supply, with limited fuel supplies to run back up power systems, or that rely on portable back up power will have limited capacity to continue to operate, and therefore will have lower adaptive capacity. Stations supplied by on-site generators will have higher adaptive capacity then those supplied by portable backup power as the portable units may be in demand or it may not be possible to transport them to the pump station in a timely manner.

Depending on their size, location and design, pump stations could be reengineered to improve their capacity to accommodate or adjust to storm events and tidal inundation. It is less likely that pump stations would be relocated; depending on the size of the facility, capital replacement costs can be fairly high and there may not be a feasible or appropriate alternative site.

<u>Wastewater Systems</u>

EBMUD

The entire EBMUD service area within the ART project area, including the private sewer laterals and community-owned collection systems, is sensitive to storm event flooding and tidal inundation, and to varying degrees elevated groundwater levels. As a whole, the system is sensitive to additional wet weather flows, whether from rainfall during a storm event, flooding due to tidal inundation, or elevated groundwater. Currently, EBMUD is prohibited from discharging directly from their wet weather facilities; the wastewater must be stored and returned to the interceptor system for conveyance to the WWTP[6]. Additional infiltration or

[6] In January 2009, the U.S. Environmental Protection Agency (EPA) and the San Francisco Bay Regional Water Quality Control Board (RWQCB) issued a National Pollutant Discharge Elimination System (NPDES) permit prohibiting any discharges from the wet weather facilities.

inflow due to sea level rise or storm events will exacerbate the existing challenges of handling wet weather flows in compliance with the current regulatory requirements.

Although not individually evaluated, sewer pipelines (laterals, collectors, interceptors, and force mains) are sensitive to increases in liquefaction potential caused by elevated groundwater levels. The entire ART project area has high seismic vulnerability, and the northern portion of the project area – in particular the shoreline of Emeryville, Oakland, and Alameda, and filled areas at the Oakland International Airport – has a very high liquefaction susceptibility rating[7]. Liquefaction and lateral spreading during earthquakes may cause damage to buried pipelines. If groundwater levels rise, there will be a greater likelihood of liquefaction, increasing the potential for damage to buried assets such as sewer pipelines during a seismic event.

Overall, the EBMUD service area has limited adaptive capacity. There is minimal redundancy among the EBMUD system components, and only some facilities have the potential to maintain function if compromised. For example, the smaller pump stations could be kept functional through the use of backup power or portable pumping, but probably only for a short time. Most of the system components have moderate to high O&M and capital replacement costs, and redesign or relocation would require not only significant financial investment but also regulatory review by a number of regional and local agencies.

Lastly, wastewater treatment is provided by EBMUD, whereas the seven communities and one sanitary district within the service area provide conveyance of flows. This situation adds a layer of complexity to the governance, O&M, capital improvement, and financing decision-making that would need to occur to improve the system's ability to accommodate or adjust to the impacts of climate change.

There is already the need for coordination among the service providers, in particular to reduce wet weather flows. EBMUD and the community systems within its service area can reduce wet weather flows (I/I) by investing in capital improvement projects such as pipeline rehabilitation, elimination of improper connections, and replacement of sewer manhole covers. While the agencies may have the ability to raise funds for these and other infrastructure projects, there is pressure to maintain reasonable rates for the users.

Efforts throughout the service area are underway to improve wet weather flows from private properties. The Regional Private Sewer Lateral Ordinance[8] requires inspection and replacement of private sewer laterals for properties in the EBMUD service area that are transferred or that change the size of their water meter, and for building or remodeling in excess of $100,000. This ordinance will help to reduce wet weather flows but is likely to do so slowly, and depends on the health of the real estate and construction markets.

EBDA

The entire EBDA service area within the ART project area, including the private sewer laterals and community-collection systems, is sensitive to storm event flooding and tidal inundation, and, to varying degrees, elevated groundwater. The system as a whole is sensitive to additional wet weather flows, whether from rainfall during a storm event, flooding due to tidal inundation, or elevated groundwater levels.

Currently, during peak wet weather flows the EBDA disposal system may not have capacity to accommodate all peak daily wet weather flow from LAVWMA. In such instances, LAVWMA is

[7] Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, November 2011, Chapter 3.
[8] http://www.eastbaypsl.com/eastbaypsl/index.html

authorized to discharge to San Lorenzo Creek, but this can be avoided by reducing or suspending flow from Zone 7 Water Agency[9]. Additionally, Wet weather flows from I/I can exceed the capacity of individual facilities, although the sensitivity to wet weather flows varies among the EBDA member agencies (see Table 1).

The EBDA Joint Outfall is sensitive to extreme tides such as those that occur during storm events. During such tides, hydraulic constraints limit the conveyance and discharge of treated wastewater from OLSD and San Leandro to the deepwater outfall, although the last time this occurred was in 1998 during a 25-year return period storm[6].

Lastly, as discussed above, sewer pipelines (laterals, collectors, interceptors, and force mains) are sensitive to increases in liquefaction potential caused by elevated groundwater levels. The entire ART project area has high seismic vulnerability, and the southern portion, including San Leandro, Hayward, and Union City, has a moderate liquefaction susceptibility rating[10]. Liquefaction and lateral spreading during earthquakes have caused damage to buried pipelines. If groundwater levels rise, the likelihood of liquefaction will increase, making damage to buried assets such as sewer pipelines more likely if a seismic event occurs.

The EBDA service area as a whole has some adaptive capacity, although this is limited by constraints on the individual system components (as described in the section above) and the complex interconnections of ownership, operation, governance, and financing. The EBDA system includes components that are owned and operated by multiple agencies and service providers. Both EBDA and LAVWMA are JPAs, and there is a contractual agreement between the two agencies to monitor, combine, and discharge treated wastewater. This existing governance and decision-making structure provides EBDA with a greater capacity to accommodate or adjust to climate impacts if they were to occur, or improve their capacity to do so in the future.

The EBDA system has moderate capacity to accommodate wet weather flows and maintain function during extreme storm events. For example, if the capacity of the Joint Outfall were reduced during an extreme tide, a portion of treated wastewater from OLSD and San Leandro can bypass the EBDA system to be dechlorinated and discharged to the Bay via overflow weirs. To minimize discharge from these bypasses, all available alternative measures are implemented first, following a set of joint EBDA/LAVWMA Standard Operating Procedures. In addition to these measures, EBDA and its member agencies are working to improve adaptive capacity by developing long-term flow capacity alternatives to manage wet weather flows.

Consequences

The potential consequences of the climate impacts are considered for the system of wastewater assets as a whole, including the communities served. Consequences are the magnitude of the effects on the economy, society, environment, and governance if an impact occurs. Factors that inform the magnitude of the potential consequences include the type and severity of the impact on O&M or capital improvement costs, the size and demographics of affected communities, the potential impact on employers and employees, and the type of natural resources affected.

---

[9] LAVWMA wet weather flows may be reduced by the suspension of the Zone 7 groundwater reverse osmosis reject flow to DSRSD, which can be interrupted. East Bay Dischargers Authority, EBDA Common Outfall, Order NO. R2-2012-0004, Attachment F - Fact Sheet.

[10] Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, November 2011, Chapter 3.

Many of the wastewater assets evaluated have the capacity to accommodate or adjust to small amounts of flooding, and therefore the overall consequences would be fairly low. The majority of the assets evaluated do not have the capacity to handle large, frequent, or severe storm event flooding, and overall the wastewater system has limited capacity to accommodate additional groundwater infiltration during wet weather. If the wastewater facilities were compromised, there would likely be a disruption in services resulting in sewage overflows and backups into basements, streets, emergency overflow areas, and the Bay. The consequence of disruption in wastewater services on the economy, society, environment, and governance is discussed below.

Economy

If the system of wastewater assets were to be adversely affected by storm flooding, tidal inundation, or elevated groundwater, the economic consequences will depend on the components affected. In general, wastewater assets have moderate to high capital replacement costs, and their redesign or relocation (if even feasible) would require significant (multi-billion dollar) investment. Additionally, many of the assets have moderate to high O&M costs, and, depending on the extent of the impact, would require significant financial resources to be returned to full function. However, some of the smaller pump stations, particular components of the WWTPs, and the emergency overflow structures have relatively low O&M costs.

The economic consequences could be significant not only to the agencies that own and operate the facilities, but to the surrounding community as a whole. Failure of the wastewater system will not only affect residential communities and commercial enterprises, but also will adversely affect industrial facilities that require sewer service to operate. The overall economic consequences due to loss of industrial production and employment disruption could be quite significant depending on the duration and extent of the shutdown. Additionally, the adverse impact on economic activity could be widespread depending on the type and duration of service disruption. Not only workplaces, but also access to community services and facilities could be affected, leading to significant cumulative impacts on economic activity.

Society

The consequences of a failure, either partial or total, of the wastewater system could result in very significant public health costs. Disruption of sewer service or failure of particular wastewater system components could result in backups in the community collection system or sewer laterals that may result in overflows of raw sewage into basements and streets. The result may be exposure of the public to disease-causing microorganisms (pathogens), requiring decontamination, cleanup, and repair or rehabilitation of affected areas.

Additionally, there could be overflows or discharges of treated or partially treated wastewater, or chlorinated wastewater from a disabled WWTP, wet weather facility, or dechlorination facility. This could result in limitations on the use of shoreline recreational resources such as the Bay Trail, boat launches, and fishing piers, as well as contact recreation such as swimming or boating in areas near discharge locations.

Environment

The magnitude of the environmental consequences depends on the wastewater asset that is disrupted or fails. For example, failure of the wastewater conveyance system, such as the interceptor sewer lines and pumps, could result in the discharge of untreated wastewater through overflow of raw or partially treated sewage. Depending on where the overflow is – for example, into the nearshore waters of the Bay, a tidal creek, or estuaries – and when the failure occurs, such as at low tide when there is minimal dilution or mixing, the consequences could be significant for the Bay ecosystem. Pathogens, organic loading, nutrients, and toxics in untreated wastewater could cause a variety of adverse impacts on the Bay's aquatic resources.

If overflows are discharged to natural systems, such as managed wetlands or tidal marsh, the magnitude of the consequences could be reduced. For example, the Alvarado Treatment Plant, operated by USD, has the ability to discharge limited overflows into the nearby Eden Landing marsh or the Hayward Marsh where treated wastewater is used as a freshwater source. Access to a managed wetland or tidal marsh system, which inherently has some capacity for natural treatment, could reduce the impact on the local Bay ecosystem for a period of time.

Failure to dechlorinate treated wastewater from the WWTP prior to discharge will have varying consequences depending on where the impact occurs. If chlorinated treated wastewater is discharged to emergency overflow or to deepwater outfalls, there could be localized impacts such as fish kills or impacts to threatened or endangered species as the water quality standards for discharge will not be met.

Governance

The governance consequences will depend on the extent of the impact, and perhaps more importantly, the location of the impact. For example, if the entire wastewater service area including private laterals, community collection systems, and agency operated conveyance, treatment and discharge facilities, is affected, the complex mixture of owners and operators will pose significant legal, regulatory, and decision-making challenges.

For example, if a wet weather facility is adversely affected the magnitude of the governance consequences will be high. This is because even though the facility is owned and operated by a single agency, the underlying need for the facility is due to larger, service area wide issues. Since expanding these facilities is not a likely solution, and reducing the use or need for the facility (e.g., by reducing wet weather flows system wide) will require significant inter-agency and cross-jurisdictional coordination. Alternatively, if a single agency's pump station is affected and that agency has the existing authority and financing necessary to make required improvements, then the magnitude of the governance consequences will be less.

There could also be significant governance challenges in continuing to meet current regulatory requirements, or in meeting new or changing requirements in the future. Facing these challenges in light of potential impacts due to a changing climate may require new operations or procedures, technologies, or financing strategies, in addition to continued multi-agency, cross-jurisdictional coordination.

Lastly, many of the wastewater assets are currently protected from storm event flooding by shore protection assets, e.g., levees and earth berms, that are owned and operated by others, and that are subject to various degrees of local, regional, state, and federal regulation. There will be significant coordination, financing, and decision-making challenges if these shore protection systems fail or are in need of enhancement or repair. This will pose a significant governance challenge that will affect not only the wastewater service providers, but many of the shoreline assets and communities included in the ART project as well.

Key Findings

There are five wastewater treatment plants in the ART project area. None are exposed to tidal inundation with 16 inches of sea level rise, but three are exposed to up to three feet of inundation from storm event flooding (Oro Loma Sanitary District, San Leandro, and Union Sanitary District). With 55 inches of sea level rise, four wastewater treatment plants will be exposed to tidal inundation, although only one quarter of the EBMUD main wastewater treatment footprint is exposed. All are exposed to storm event flooding. Wastewater treatment plants have a moderate ability to accommodate or adjust to infrequent, short duration flooding, but a very low capacity to cope with more frequent or longer duration inundation.

Additionally, due to their size, complexity, and the financial investment required to construct, operate and maintain them, there is little to no duplication or redundancy in wastewater treatment plants and their associated facilities. There would be significant consequences from operational failures, overflows, and backups that result from sea level rise or storm events that compromise the function of any of the five treatment plants assessed.

Of the 27 wastewater pump stations evaluated in the ART project area, only East Bay Municipal Utility District's (EBMUD's) pump station G is exposed to tidal inundation with 16 inches of sea level rise. This pump station, located on Doolittle Drive near the Oakland International Airport, is exposed to approximately four feet of inundation with the new high tide and seven feet during storm events. While pump stations have the capacity to accommodate small amounts of flooding for short durations, four to seven feet of inundation would incapacitate this station. Failure of any of the pump stations, which lift wastewater throughout the collection system as it is conveyed from source to treatment plant, could have significant consequences on public health or nearby sensitive natural resources.

In general, small- to medium- sized pump stations (e.g., less than 10 million gallons per day) have greater adaptive capacity than larger pump stations because portable pumps may be able to prevent operational failures if a suitable power supply is available and the flooding has not compromised access to the station. Larger pump stations such as the East Bay Dischargers Authority's (EBDA's) five pump stations and EMBUD's pump station H, can carry flows that are too large to be handled by portable pumps.

The EBMUD and EBDA service areas, including the private sewer laterals and community-owned collection systems, are sensitive to additional wet weather flows. While there are current practices and facilities in place to manage wet weather flows, some of these practices and facilities are themselves vulnerable to sea level rise. For example, one of EBMUD's two wet weather facilities is exposed to storm events with 16 inches of sea level rise, and both are exposed to storm events with 55 inches of sea level rise. In addition, the capacity of the EBDA system to discharge to the deepwater outfall is sensitive to extreme tides, which can limit the conveyance and discharge of treated wastewater from Oro Loma Sanitary District and San Leandro. In this case treated wastewater can be discharged to the Bay via overflow weirs, which may affect recreational assets such as the Bay Trail and potentially sensitive natural resources.

There are a number of wastewater facilities or facility components that are highly sensitive due to their design and construction. For example, facilities that are open to the inflow of flood waters, such as EBMUD's wet weather facilities, Hayward's final effluent channel, and EBDA's Oro Loma pump station that has open wet wells, are highly sensitive to tidal inundation or storm event flooding. In addition, most wastewater facilities have significant underground components that are highly susceptible to even low levels of flooding. For example any equipment with electrical components such as motors, instrumentation and motor control centers are particularly sensitive and not operable if exposed to water. Lastly, wastewater facilities require power, and while backup power can mitigate the impacts of power failures, backup power requires access to the exposed asset and the ability to maintain a supply of fuel.

Chapter 13. Stormwater Management

Stormwater runoff is generated when rain or snowmelt flows over land or impervious surfaces and does not infiltrate into the ground. Stormwater infrastructure consists of storm drains that collect urban runoff and underground pipes that carry water to a discharge or outlet location, such as a flood control channel (Figure 1). Flood control infrastructure includes creeks, culverts, and channels that drain to the Bay, as well as pump stations where gravity alone cannot drain an area, especially during high tides. Mostly located in low–lying areas near the Bay, pump stations receive water from the conveyance network – that is, the pipes, creeks, and channels – and pump it to an elevation high enough to allow it to then flow by gravity into San Francisco Bay. In the ART project area, stormwater infrastructure is owned and managed by the cities, and flood control infrastructure, through which stormwater ultimately discharges to the Bay, is owned and operated by Alameda County. While precipitation and associated stormwater can cause flooding directly, this assessment addresses only the impacts resulting from the interaction of sea level rise with the stormwater management system – that is, the drains, conveyance network, pump stations, and outfalls that carry stormwater to the Bay. This chapter does not address the potential impacts of climate change on precipitation.

Figure 1. Overview of urban stormwater infrastructure, from curb to Bay. Source: Adapted from www.lastormwater.org/siteorg/general/lastrmdrn.htm

Stormwater is regulated through National Pollution Discharge Elimination System (NPDES) permits under the federal Clean Water Act (CWA), which directs states to adopt and enforce water quality standards, establish maximum allowable pollution levels for water bodies, and monitor and regulate discharges into water bodies. The State Water Resources Control Board, which has overall responsibility for water quality, delegates the administration of NPDES permits to its regional boards. The San Francisco Bay Regional Water Quality Control Board (Regional Board) is therefore in charge of water quality permitting activities for the ART project area. The cities, unincorporated areas, and flood control districts in Alameda County all share one NPDES permit through a consortium of 17 agencies called the Alameda Countywide Clean Water Program (ACCWP).

In the ART project area, stormwater does not receive any significant treatment prior to discharge aside from catch basin sumps that collect coarse-grained sediment, and grates on some outfalls that collect trash and other debris. This means that stormwater can carry a host of pollutants to the Bay, including oil and grease, metals, bacteria, nutrients, and suspended solids (Alameda Local Agency Formation Commission, 2005). To improve the quality of water in the stormwater and flood control system, and to comply with ACCWP's NPDES permit, the cities and counties perform regular maintenance of their infrastructure, including removal of blockages and cleaning inlets and basins, and preventative activities such as street sweeping, public outreach, and inspections for illicit discharge. "Pre-treatment" measures such as vegetated swales, retention ponds, and tree box filters are encouraged and to some extent required as part of the NPDES permit. Such measures also help slow water on its way to the Bay, reducing peak flows through the system.

With the exception of the City of Alameda, where stormwater flows to the Bay in city-owned pipes and channels, the stormwater from cities in the ART project area is routed into a regional flood control system through which it ultimately reaches the Bay. This system is owned and maintained by the Alameda County Flood Control and Water Conservation District (ACFCWCD), which is divided into nine zones, seven of which lie fully or partially in the ART project area (Figure 2 and Table 1). The zones are based on major watershed areas and are treated as separate financial entities for the purposes of maintaining and constructing facilities and for levying assessments. ACFCWCD has capital improvement programs in each zone that budget and plan for major improvements such as building and repairing levees and floodwalls and de-silting channels.

Figure 2. ACFCWCD flood zones, pump stations, and major creeks and channels in the ART project area.

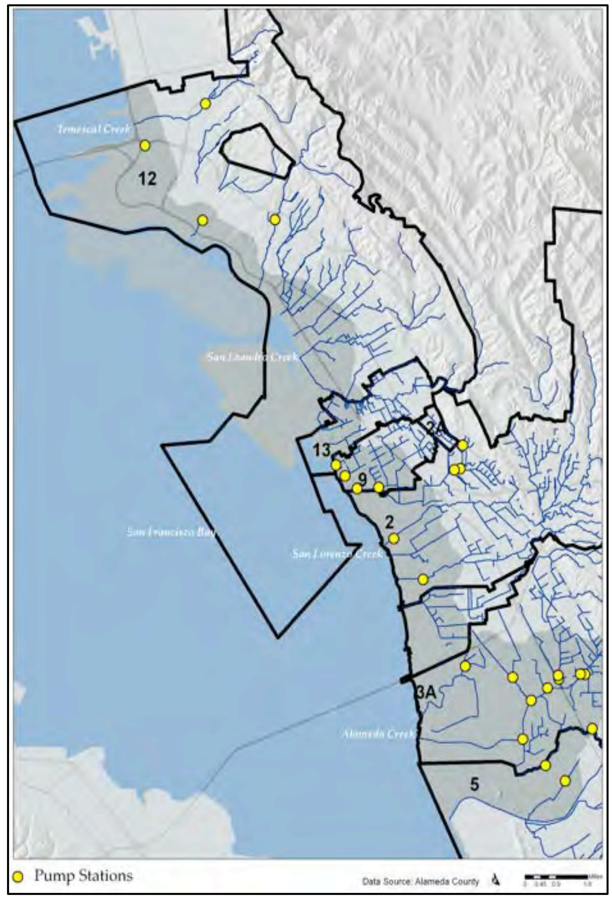


Table 1. Overview of ACFCWCD stormwater drainage systems; flood zones in the ART project area are listed from north to south.

Zone	Communities	Area (acres)	Major Creeks	Pump Stations
12	Emeryville, Oakland, San Leandro	38,000	Temescal, Sausal, Peralta, Lion, Arroyo Viejo, and Elmhurst	5
13	San Leandro	3,200	San Leandro	--
9	San Leandro	2,482		4
2	Hayward, San Leandro, Castro Valley, San Lorenzo, Ashland, Cherryland	40,390	San Lorenzo, Sulphur	--
4	Hayward, Mohrland, Russell City	2,960		--
3A	Hayward, Union City	19,700	Old Alameda, Mt. Eden	10
5	Fremont, Newark, Union City	45,500	Alameda, Old Alameda	3

In the City of Alameda, the stormwater system is divided into four drainage areas on each island (Alameda and Bay Farm), forming a total of eight drainage sub-areas. These sub-areas contain pipes, pumps, culverts, outlets and lagoons, owned and operated by the City, which ultimately discharge into San Francisco Bay. Figure 3 shows the sub-areas and Table 2 summarizes the stormwater infrastructure in each sub-area.

Figure 3. City of Alameda stormwater management sub-areas (Source: Schaaf and Wheeler, 2008).

Table 2. Stormwater management infrastructure in City of Alameda sub-areas

Drainage Sub-area	Area (acres)	Miles of Pipes Greater than 12”	Number of Outlets	Pump Stations
Alameda Eastside	448	5	14	1
Alameda North-Central	704	6	11	0
Alameda Northside	1472	25	12	6
Alameda South	1472	11	23	3
Bay Farm East	576	5	2	1
Bay Farm North	243	4	4	1
Bay Farm Central	371	11	33	0
Bay Farm South	544	8	5	1

Exposure

Exposure is the extent to which an asset, in this case, part of the stormwater management system, experiences a specific climate change impact such as storm event flooding, tidal inundation, or elevated groundwater. This report analyzes the exposure of the stormwater system in the ART project area to two sea level rise projections and three Bay water levels. The two sea level rise projections, 16 inches (40 cm) and 55 inches (140 cm), correlate approximately to mid- and end-of-century. These projections were coupled with three Bay water levels: the highest average daily high tide represented by mean higher high water (MHHW), hereafter "high tide" or "daily high tide;" the 100-year extreme water level, also known as the 100-year stillwater elevation (100-year SWEL), hereafter "100-year storm" or "storm event;" and the 100-year extreme water level coupled with wind-driven waves, hereafter "storm event with wind waves" or "wind waves." These water levels were selected because they represent a reasonable range of potential Bay conditions that will affect flooding and inundation along the shoreline. For more information about sea level rise projections and Bay water levels evaluated see Chapters 1 and 2.

The locations and elevations of the pump stations were available in GIS, allowing evaluation of the exposure of each pump station to the daily high tide and storm event flooding. The exposure of the pump stations was determined within a circular 164-foot (50-meter) diameter footprint centered on the point location of the station (see Appendix C). This approach was verified as being representative of the approximate footprint of most assets evaluated in this manner. The average depth of inundation was calculated for the daily high tide and storm event scenarios. Whether the asset was exposed to wind waves only, or was within a disconnected low-lying area[1], was evaluated in a binary, i.e., yes versus no, analysis. Table 3 summarizes the exposure of ACFCWCD pump stations. A similar, GIS-based analysis of pump stations in the City of Alameda was not conducted as part of this assessment. The City has conducted its own stormwater system sea level rise vulnerability assessment, which is discussed in the box in the sensitivity and adaptive capacity section, below.

Beyond the ACFCWCD pump stations, very little GIS data were available for exposure analysis. Critical information, such as the location and elevation of stormwater outfalls into the Bay, was not available and therefore was not analyzed. Likewise, other components such as creeks, channels, and pipes, were not evaluated. The exposure of these features will vary along their extent and will depend on their geometry. The dynamic hydraulic modeling that would be necessary to analyze the interaction of Bay water levels with stormwater in these system components was not performed. However, because of their direct connection with the Bay, these features will be affected by the new daily high tide and storm events. For example, the mouth of Temescal Creek, a flood control channel, is currently subject to tidal action ranging from three to six feet every day (City of Emeryville, 2009). With sea level rise, water depths in Temescal Creek and other creeks and channels will increase, and some outfalls may be underwater. This could result in flooding (overtopping of creeks and channels, and ponding around inlets to pipes), as there may be insufficient storage in these creeks and channels to hold the stormwater until it can be released into the Bay.

Figure 2, above, shows the ACFCWCD zones, pump stations, and major flood control creeks and channels in the ART project area. Without vertical elevation data of the stormwater conveyance features or dynamic modeling, this figure serves simply as a first glance at the

[1] Disconnected low-lying areas are at the same elevation or are lower than an adjacent inundated area. Assets in these areas are not considered exposed because a topographic feature such as a railroad or road embankment should prevent inundation. However, they could be exposed if the protective feature fails. See Chapter 2 for a more detailed explanation.

locations of some stormwater system features within each zone. The next section describes each of the flood zones and details the exposure of the pump stations within each zone (Table 3). However, as stated above, while analysis of pump station exposure is useful in determining the exposure of valuable infrastructure, it does not provide a comprehensive picture of the vulnerability of the stormwater management system, overall, to climate impacts. Further work, such as that conducted by the City of Alameda, and other studies by ACFCWCD underway, should include analysis of the exposure of outfalls and other conveyance features.

ACFCWCD Zones

Figure 4. Pump components of the Ettie Street Pump Station, Oakland.

Zone 12 is 38,000 acres[2] and drains Emeryville, Oakland, and part of San Leandro. It includes a long stretch of shoreline (comprising nearly half of the mainland extent of the ART project area), as well as a large inland area. Stormwater is drained through 12 creeks, more than ten miles of earth and concrete channels, and 49 miles of underground pipes. The major creeks draining into the Bay are San Leandro, Elmhurst, Arroyo Viejo, Lion, Sausal, Temescal, and Peralta. Zone 12 has five pump stations, two of which – Ettie Street (Figure 4) and Lake Merritt – are in the ART project area. With 16 inches of sea level rise, Ettie Street pump station, near the I-80 and I-580 interchange in West Oakland, will be exposed to wind waves during a 100-year storm. At 55 inches of sea level rise, Ettie Street pump station will be exposed to 2 feet of flooding from a 100-year storm event, as well as wind waves. Lake Merritt pump station is not exposed to any of the scenarios.

Zone 13 is 3,200 acres and drains part of San Leandro. The zone consists mostly of lowlands and is bordered by Zone 12 near the base of the hills to the east. San Leandro Creek runs through Zone 13, which is also served by a few miles of earth and concrete channels and 33 miles of underground pipes. Zone 13 does not have any pump stations and relies on gravity drainage to remove stormwater.

Zone 9 is 2,482 acres and drains part of San Leandro. Like Zone 13, it is primarily lowlands and is bordered to the east by Zone 2A (outside of the subregion). It has three miles of natural creeks and approximately three miles of earth and concrete channels. Zone 9 has four pump stations, three along the shoreline and one slightly inland. Pump stations F and H are in disconnected low-lying areas that could be exposed to the daily high tide with 16 inches of sea level rise. All four stations will be exposed to 1 to 2 feet of flooding in a 100-year storm, with additional wind wave impacts. With 55 inches of sea level rise, all four pump stations will be exposed to 2 to 3 feet of inundation by the daily high tide, and 4 to 5 feet in a 100-year storm, with additional wind wave impacts.

Zone 2 is 40,390 acres and serves parts of Hayward and San Leandro, as well as Castro Valley, San Lorenzo, Ashland, and Cherryland. It includes a large upland area in addition to shoreline.

[2] The ACFCWCD website gives an area of 51,200 acres; the figure presented in this report removes the portion of the flood zone in the shapefile provided by Alameda County which is already part of the Bay; that is, a portion of the 51,200 acres is water, not land, and therefore was removed for this analysis.

Zone 2 is drained by over 80 miles of creeks, 17 miles of earth and concrete channels, and 44 miles of underground pipes. Among the 12 creeks in the zone, the major ones that flow to the Bay are San Lorenzo Creek and Sulphur Creek. Two drainage canals, Bockman and Estudillo, also drain directly into the Bay. Zone 2 has two pump stations near the shoreline. With 16 inches of sea level rise, Sulphur Creek pump station will be exposed to wind waves during a 100-year storm. With 55 inches of sea level rise, both pump stations will be exposed to 1 to 2 feet of inundation from the daily high tide and 3 to 4 feet of flooding in a 100-year storm, with additional wind wave impacts.

Zone 4 is 2,960 acres and serves part of the City of Hayward, as well as the communities of Mohrland and Russell City. It is a small, low-lying zone, bordered to the north by Zone 2, and to the south and east by Zone 3A. Zone 4 has fewer than two miles of creeks, four miles of earth and concrete channels, and nine miles of underground pipes. There are no pump stations, and the creeks and channels in this zone drain to the Bay through a channel that border with Zone 2.

Zone 3A is 19,700 acres and serves a number of communities, including parts of Hayward and Union City. Much of Zone 3A is very low-lying and includes salt ponds as well as some upland portions of Hayward. There are 21 miles of creeks in the Zone, including Old Alameda Creek and Mt. Eden Creek, which flow through salt ponds to the Bay; 25 miles of earth and concrete channels; and 43 miles of underground pipes. It also has ten pump stations within the ART project area, both along the shore and inland. With 16 inches of sea level rise, Besco and Alvarado pump stations will be inundated by 4 and 2 feet, respectively, by the new daily high tide. They will be flooded by 6 and 3 feet in a 100-year storm event and will also be exposed to wind waves. All of the other pump stations in the zone, except for Stratford and Westview, will be exposed to wind waves. Pump stations A-2[3] and Ameron are in disconnected low-lying areas that could be exposed to 100-year storm event flooding; the disconnected low-lying area where A-2 is located could also be exposed to the daily high tide. With 55 inches of sea level rise, Eden Landing, Besco, Ameron, Alvarado, and A-2 pump stations will be exposed to 1 to 6 feet of flooding by the daily high tide. All but Stratford, Westview, and Ruus Road will be exposed to 1 to 9 feet of flooding by a 100-year storm event, and all will be exposed to wind waves.

Zone 5 covers 45,440 acres and serves parts of Fremont, Newark, and Union City. It is mostly low-lying but drains some of the hills of Union City and Fremont. The zone has 37 miles of creeks, including Alameda and Old Alameda, as well as more than 40 miles of earth and concrete channels and 49 miles of underground pipes. It is served by three pump stations, two of which – J2 and J3 – are in the ART project area. Both pump stations are in disconnected low-lying areas that could be exposed to the 100-year storm event with 16 inches of sea level rise. Both will be exposed to wind waves during a 100-year storm. With 55 inches of sea level rise, the pump stations are exposed to 2 to 3 feet of inundation by the daily high tide, and 4 to 6 feet of flooding in a 100-year storm, with additional impacts likely due to wind waves.

[3] A-2 pump station is not identified on ACFCWCD's website, but the GIS data used for this analysis shows this as being within this flood zone.

Table 3. Exposure of ACFCWCD pump stations to the daily high tide and storm event flooding with 16 and 55 inches of sea level rise.

		16" SLR			55" SLR		
		Daily high tide	Storm Event		Daily high tide	Storm Event	
Name	Zone	Average depth (ft)	Average depth (ft)	Exposed to wind waves only	Average depth (ft)	Average depth (ft)	Exposed to wind waves only
Lake Merritt	12						
Ettie St.	12			Yes		2	
Line H	9		2		2	5	
Line F	9		1		2	4	
Belvedere	9		1		2	5	
Line D-1	9		2		3	5	
Roberts Landing	2				1	3	
Sulphur Creek	2				2	4	
Eden Landing	3A		1		2	4	
Besco	3A	4	6		6	9	
Ameron	3A				1	3	
Stratford	3A						Yes
Industrial	3A			Yes		1	
Westview	3A						Yes
Alvarado	3A	2	3		4	6	
Ruus Road	3A			Yes			Yes
Eden Shores	3A			Yes		3	
A-2	3A				1	4	
J-3	5				3	6	
J-2	5				2	4	

Sensitivity and Adaptive Capacity

The sensitivity and adaptive capacity of stormwater infrastructure in the ART project area to three potential climate impacts that could occur due to sea level rise was assessed. The three climate impacts considered are:

- More frequent or longer duration flooding during storm events
- Permanent or frequent inundation by the daily high tide
- Elevated groundwater levels and saltwater intrusion

Sensitivity is the degree to which an asset or entire system (e.g., pump stations, pipes, channels, or entire watershed) would be physically or functionally impaired if exposed to a climate impact. Adaptive capacity is the ability for an asset or system to accommodate or adjust to a climate impact and maintain or quickly resume its primary function.

The stormwater management systems in the ART project area have fairly high sensitivity to all three climate impacts, given their function and direct contact with the Bay. Characteristics of the individual components as well as the overall system contribute to sensitivity. One of the features of the system that makes it sensitive is its reliance on gravity for drainage. As sea levels rise, there will be less of a gradient between the source of the stormwater and its eventual destination, and some of the outfalls will be below sea level during high tide or a storm event. This means that Bay water will enter the stormwater systems and travel up creeks, channels, and pipes. If elevated Bay water levels coincide with a precipitation event, the presence of Bay water in stormwater infrastructure will reduce the system's capacity to store and convey stormwater, which could result in stormwater backing up and causing inland flooding. In addition, saltwater could corrode and otherwise damage infrastructure that is only designed to handle freshwater.

Pipes with the largest excess capacity – that is, the most room to store stormwater when precipitation coincides with high tide – will have greater adaptive capacity. Another way to increase adaptive capacity is to install check valves, such as duckbills (Figure 5), a device that only allows flow in one direction, on the outfalls to the Bay. These valves prevent Bay water from entering the system and taking up pipe capacity needed to convey and store stormwater. Where gravity drainage is insufficient, it may become necessary to install pumps, but these can have high capital improvement and operations and maintenance costs.

Figure 5. Duckbill check valve discharging water. Photo credit: Tideflex Technologies.

Pump stations are sensitive to sea level rise in several ways. They rely on sensitive electric or computerized components that would not be able to function if flooded. Pump stations cannot lift stormwater beyond their design capacity, or above certain elevations. They also require a power supply, which could be disrupted – if access to pump stations is flooded, those without sufficient backup fuel on site could be particularly sensitive. In areas that already require pumping to manage stormwater and control flooding, pumps will have to lift water above the new, elevated Bay water level, which may exceed their capacity. More frequent operation and pumping water to higher elevations will increase energy and maintenance costs and could decrease the operational life of pumps. Retrofitting, adding pumps, or bringing in portable pumps could contribute to adaptive capacity, but as noted above, this would be costly, and backup pumps may not be available. Another feature that contributes to adaptive capacity is a forced main, wherein the discharge pipe is hardened and pumped to maintain positive pressure. This enables the pipe to discharge even when the opening is underwater. The outfall for Ettie Street pump station is permanently underwater, and it is the only pump station in the ART project with a forced main. This may be an option for outfalls that will be permanently or frequently inundated, but it involves costly infrastructure.

Sensitivity and Adaptive Capacity of the City of Alameda Stormwater System

In 2008, the City of Alameda conducted a detailed study to identify sensitivity in their stormwater system (Schaaf and Wheeler, 2008). The most common cause of local flooding is leaf litter in the system, which plugs inlets and outlets and reduces the effectiveness of pump stations, and the obstruction of gutters and culverts by tree roots. Some flooding in extreme events is also caused by limited capacity within the stormwater management system. By modeling tide cycles, precipitation, runoff, and other factors, the City determined where improvements to the storm drain system are necessary to provide a 10-year level of service. This is the ability to meet certain criteria – such as pipe capacity and the level of stormwater in the street – during a 10-year storm event under current climate conditions. Areas currently in need of improvement will be particularly sensitive to sea level rise impacts, as they may already be overwhelmed by extreme events.

The study recommended a number of improvements, primarily focused on increasing the size of certain pipes in problem areas. If implemented, these improvements would contribute to adaptive capacity by providing more storage in pipes so that stormwater could be detained during high tides, when outfalls could be underwater and Bay water would cause backups.

An addendum to this study, conducted in 2009, analyzed the capacity of the system to maintain a 10-year level of service with 18 inches of sea level rise. The study concluded that additional projects would be necessary, including adjusting the recommended size of some of the pipes that were already marked for replacement and the need to expand additional pipes. In addition to recommendations on pipe size, the study evaluated the cost of implementing the initial recommendations, as well as the increased costs of recommended improvements to accommodate sea level rise. Such information is especially useful for weighing the costs and benefits of building extra capacity now or waiting until later to act. In this case, putting in slightly larger pipes than are necessary now may be more expensive in the short term, but is likely to be far less costly than replacing them again when sea level rises.

Stormwater management is also sensitive to rising groundwater. Higher groundwater levels will reduce the capacity for management practices to increase infiltration such as retention and detention, meaning that more precipitation could end up as runoff and have to be conveyed to the Bay in flood control channels and creeks. It could also reduce capacity in channels and creeks connected to the groundwater table. In addition, rising groundwater will increase the risk of liquefaction in a seismic event, which could cause underground pipes to move, bend, or break.

The sensitivity of the overall system – from the top of the watershed to discharge locations – is affected by a number of factors. The age of the stormwater infrastructure and the limited funds for repair, upgrade, and ongoing maintenance makes stormwater management very sensitive. In most parts of the ART project area, property assessments and other fees are insufficient to cover expenses for maintenance or expansion of the stormwater system, and general fund revenues must be used. Additionally, stormwater assessments are considered property-related fees under Proposition 218, so a two-thirds vote would be necessary to increase them, which limits adaptive capacity.

Regular maintenance of stormwater infrastructure, such as keeping storm drains clear of debris and trash, contributes to adaptive capacity. Such maintenance is required in NPDES permits, and the ACCWP reports regularly to the Regional Board on compliance. As mentioned above, the ACFCWCD has a capital improvement program in each zone that prioritizes and funds infrastructure repair and construction. In addition, ACFCWCD works with other entities to restore creeks in the system to a more natural condition, which can improve flood control as well as providing habitat and recreational values. The City of Alameda also has a small fund for maintenance and capital improvement, raised through the local urban runoff property tax and grants; however, this is insufficient for implementing all of the necessary improvements identified by the City in the study discussed above.

Inland flooding problems caused or exacerbated by sea level rise could perhaps be mitigated by improving stormwater management throughout each watershed, not just through flood control infrastructure. A large portion of each watershed in the ART project area is developed, and the impervious surfaces common to developed areas mean that stormwater does not infiltrate and instead makes its way to the Bay through the stormwater and flood control infrastructure. The Mediterranean climate of the area also means that, while annual precipitation is relatively low, most rainfall usually occurs within a short period of time, saturating the ground and sometimes filling the stormwater system to capacity (referred to as “surcharging”).

Efforts to reduce runoff by increasing infiltration throughout the watershed contribute to adaptive capacity. One way to achieve this is through the use of low impact development (LID) principles. One principle of LID is to capture and store water in ponds or bioswales high in the watershed, resulting in reduced and/or delayed peak discharge into downstream infrastructure. Another approach is to reduce impervious surfaces through the use of semi-pervious or pervious surfacing materials for parking areas or sidewalks, allowing more water to infiltrate rather than flowing into stormwater infrastructure. Another element of LID is to capture rainfall for later use in rain barrels or rain gardens.

While LID can be implemented on a case-by-case basis, integrating it into a stormwater management system takes time, planning, and money, and requires the participation of the entire watershed. As explained above, ACFCWCD is responsible for the flood control infrastructure, while the cities are responsible for the initial capture of stormwater. The generation of stormwater is highly dependent on the amount of pervious surface where precipitation falls. Development and land use are determined by a number of entities, and there is currently little coordination between ACFCWCD and the cities and others who determine land use throughout the watershed.

Some investment in LID is already taking place. As part of their NPDES Permit, for example, the cities and counties in the ART project area require new and redevelopment projects to incorporate stormwater treatment measures or Best Management Practices (BMPs) to minimize pollutants in the stormwater management system. However, this only applies to new development, redevelopment, and certain changes to the land surface in already developed sites. These areas account for a relatively small percentage of runoff in the area. Unless retrofitting ground covers and other stormwater management practices in existing developed areas becomes widespread, the majority of precipitation will still become runoff and enter the stormwater and flood control system rather than being retained or infiltrated. Over time, however, both permit-mandated LID and special projects can contribute to the retention, detention, and infiltration of stormwater in the ART project area, increasing the adaptive capacity of the stormwater management system as a whole.

Consequences

The potential consequences of the climate impacts on stormwater management are considered for the ART project area. Consequences are the magnitude of the economic, social, environmental, and governance effects if an impact occurs. Factors that inform the magnitude of the potential consequences include the severity of the impact on operations and maintenance or capital improvement costs, the size and demographics of the population affected, and the types of natural resources affected.

Economy

If the stormwater system is impaired by sea level rise, either through storm events, tidal inundation, or rising groundwater, there will be direct and indirect economic consequences. One direct consequence is the cost of water removal, cleanup, and repairs to structures and landscapes damaged by flooding. Major flooding could also damage stormwater infrastructure itself, such as pumps, channels, inlets, and outfalls, which would then need to be repaired. In the City of Alameda, for example, while flooding has historically not caused significant structural damage, it has required City staff resources to prepare for, handle, and recover from flood events (Schaaf and Wheeler, 2008). Saltwater intrusion could also cause economic consequences by damaging equipment through corrosion. An indirect economic consequence is the business or productivity that could be lost due to commercial buildings being inaccessible if they or the roads required to reach them are flooded. For example, most of Emeryville's main shopping areas are near the shoreline. If they are forced to close because of flooding, or if workers or customers can't reach them due to road closures, they would lose business, which could result in economic losses for the city and the region.

Society

The social consequences of an impaired stormwater system are similar to the economic ones – people's lives will be disrupted if their homes or places of employment are damaged or closed, or if they are isolated due to road closures. Flooding could impede emergency response, important not only for immediate problems that could be caused by flooding, but also for medical or other emergencies that require urgent attention. If floodwaters are not removed quickly, they could become breeding grounds for mosquitoes and other disease vectors. There are also equity concerns, as low-lying areas in the ART project area that currently need to be pumped to maintain positive drainage tend to have lower-income residents. These residents may be particularly vulnerable, especially where there are language barriers or poorly maintained infrastructure that could exacerbate the problem.

Environment

Environmental concerns related to stormwater include the redistribution of contaminants that water picks up from the land surface. An impaired stormwater system would distribute contaminated runoff differently – rather than flowing directly to the Bay, pollutants could be deposited wherever the floodwaters flow. In addition, floods could destroy sensitive habitats or areas under restoration, or redistribute pollutants from contaminated lands or hazardous materials sites into natural areas.

Governance

A key governance issue related to stormwater is the need to manage it across the entire watershed, while jurisdiction over each watershed is divided across cities and counties. As noted above, with the exception of the city of Alameda, all of the cities in the ART project area ultimately channel their stormwater into Alameda County's floodwater infrastructure. While ACFCWCD zones are roughly based on watersheds, each watershed (and zone) is made up of portions of several cities and unincorporated communities, which manage the initial stormwater capture and have a role in determining land use, which in turn affects the degree of development and pervious surface in the watershed. The number of jurisdictions involved, and the need for coordination between the upper watersheds and the point of discharge, can make it difficult to prioritize and implement management strategies such as LID. If one adaptation strategy is to reduce peak flows entering this system, Alameda County will need to coordinate with each of the cities to improve stormwater management at all levels of the watershed.

Key Findings

Stormwater infrastructure consists of storm drains that collect urban runoff and underground pipes that convey flows to a discharge outlet. Stormwater outlets are often located with flood control infrastructure along the Bay shoreline. Flood control infrastructure includes creeks, culverts, and channels that drain to the Bay. In some cases there are also associated pump stations where drainage cannot be achieved by gravity alone. The capacity to discharge stormwater is sensitive to sea level rise and will depend on the elevation and location of the outlet and the storage and flow capacity of the underground pipe system. If elevated Bay water levels coincide with a precipitation event, the presence of Bay water in stormwater infrastructure will reduce storage in the system, which could result in stormwater backing up and causing inland flooding.

A total of 20 pump stations in the ART project area, excluding the City of Alameda (which has conducted its own analysis and identified parts of the system that should be upgraded to accommodate sea level rise), were evaluated. With 16 inches of sea level rise, very few pump stations are exposed to the daily high tide, but nearly all are exposed to storm event flooding or wind waves. About two thirds of the pump stations are exposed to the daily high tide with 55 inches of sea level rise, and all but one are exposed to wind waves. Pump stations are sensitive to sea level rise because they require power and may have electronic or computerized components that cannot get wet. Many also have limited adaptive capacity due to their age or ongoing need for maintenance, and funds are limited due in part to legislation that prohibits increasing property assessments to fund system improvements. Pump stations with access to a backup power supply and sufficient fuel will have higher adaptive capacity.

The lack of key data (e.g., elevation of inlets and outfalls) and modeling capacity (e.g., dynamic modeling showing the interaction of stormwater conveyance and Bay water levels) makes it difficult to fully understand the vulnerability of the stormwater system to sea level rise. Further work to identify the elevation of key features of the stormwater system, as well as modeling of Bay water and stormwater interaction within pipes, channels, and creeks, is necessary to better analyze the exposure and overall vulnerability and risk of the stormwater system.

Improvements to the stormwater system as a whole will require interagency collaboration and coordination between those responsible for the source of stormwater – the upper watersheds (managed by cities, property owners, state regulations, etc.) – and those who manage stormwater at the shoreline (e.g., ACFCWCD). Currently, there is not a framework in place to make comprehensive, watershed-based decisions to improve the adaptive capacity of stormwater and flood control infrastructure.

References

Alameda Local Agency Formation Commission. 2005. Final Municipal Service Review Volume II – Utility Services.

City of Emeryville. 2009. Emeryville General Plan Draft Environmental Impact Report.

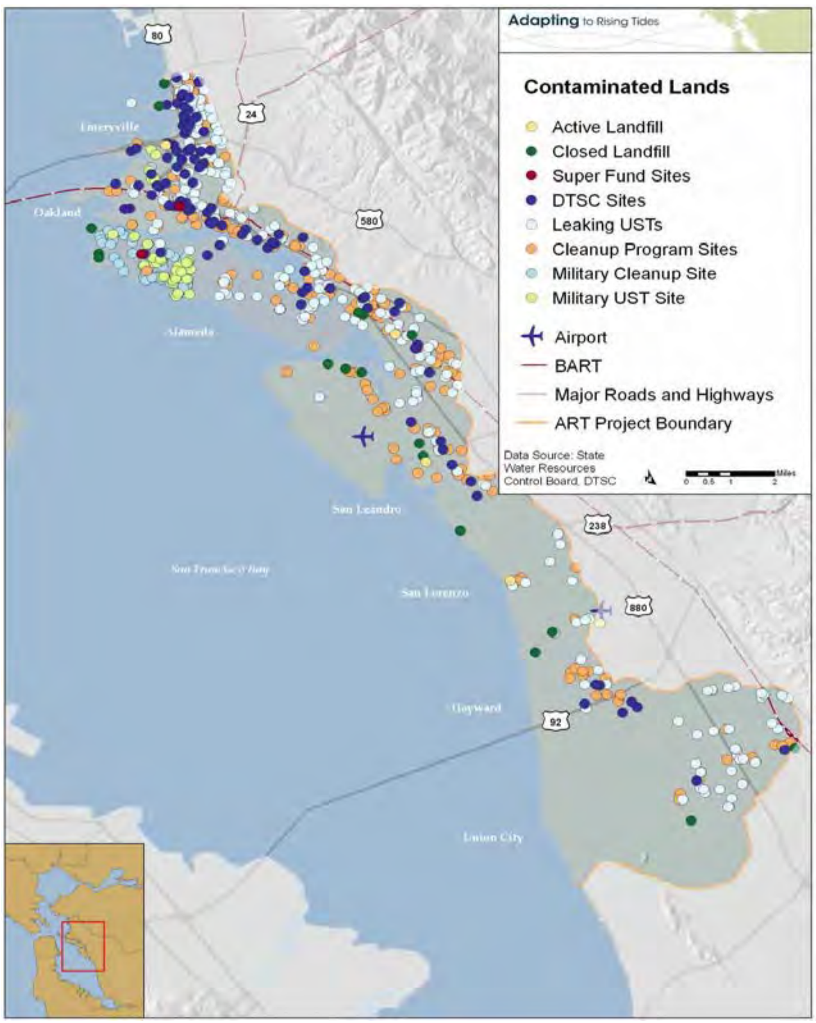
Schaaf and Wheeler. 2008. Storm Drain Master Plan, Alameda, California.

Chapter 14. Contaminated Lands

Contaminated lands are sites in the ART project area that are contaminated with materials that pose a hazard to people and/or the environment. In general, the threat posed by a contaminated site depends on its potential to release hazardous substances into the environment; the characteristics of the substances (e.g., toxicity and quantity); and people, ecosystems, and other sensitive receptors that would be affected by a release of hazardous substances.

This report identifies eight types of contaminated lands (See Figure 1 and Table 1): Federal Superfund sites; Site Cleanup Program[1] sites; Leaking Underground Storage Tanks (USTs), divided into military and non-military UST sites; Military Cleanup sites; Department of Toxic Substances Control (DTSC) sites, which include some Site Cleanup Program and UST sites; and closed and active landfills. There is some overlap across these types of sites – for example, a landfill could contain USTs, or a Superfund site could contain landfills – and agencies may share oversight responsibilities over individual sites.

Figure 1. Map of contaminated lands in ART project area, by type of site.



The two Superfund sites are the Alameda Naval Air Station, now known as Alameda Point, in Alameda, and the former AMCO Chemical Facility in West Oakland. The other types of contaminated lands are found throughout the ART project area, with clusters in certain neighborhoods or geographic areas. For example, most of the Military Cleanup Sites and Military USTs are found in Alameda Point, within and adjacent to the Alameda Naval Air Station Superfund site, or at or near the Oakland Army Base (also known as the Oakland Gateway Development site). Many of the Site Cleanup Program and DTSC sites are found in former industrial areas, such as Emeryville, West Oakland, and Downtown Oakland. A number of closed landfills are located directly along the shoreline and even protrude into the Bay. Some of them are now used as shoreline parks.

---

[1] Formerly called the Spills, Leaks, Investigation, Cleanup (SLIC) Program, the Site Cleanup Program is run by Regional Water Quality Control Boards and the State Water Resources Control Board.

Table 1. Types of contaminated lands addressed in this report and number of each type documented in the ART project area.

Type of Site	#	Description	Regulatory Agencies
Superfund	2	A federal Superfund site is an abandoned area where hazardous waste is located, possibly affecting local ecosystems or people. These areas have been designated on a National Priorities List through the federal Superfund cleanup program.	The US Environmental Protection Agency (US EPA) has primary jurisdiction over Superfund sites, with the involvement of the Regional Water Quality Control Board (RWQCB) and the State Department of Toxic Substances Control (DTSC).
Site Cleanup Program	303	Cleanup program sites are locations that have had unauthorized releases of pollutants that have contaminated soil or groundwater, and in some cases surface water and sediment.	California State Water Resources Control Board's (SWRCB) and RWQCB
Leaking UST	405	Leaking USTs are sites that have or had leaking USTs. The vast majority of leaking UST sites are contaminated with petroleum products associated with gasoline service station operation. Tetrachloroethylene (TCE) is another common contaminant from leaking USTs and is commonly associated with the dry cleaning process.	Generally under jurisdiction of SWRCB with RWQCB or DTSC as lead agency for cleanup.
Military UST	43	Military facilities with leaking USTs	SWRCB, RWQCB, and Department of Defense (DOD)
Military Cleanup	96	Sites at military facilities with water quality issues. The facilities that require environmental cleanups range from UST sites to Superfund sites, and can be part of other sites such as DTSC sites.	SWRCB, RWQCB, DOD, DTSC
DTSC	112	DTSC sites can be State Cleanup, leaking UST, or other contaminated lands sites for which the Department of Toxic Substances Control is the lead agency for cleanup.	DTSC
Landfill (closed)	15	A landfill is a solid waste management facility where waste is or once was disposed of on land or in tidal areas. Landfills do not include surface impoundments, waste piles, land treatment units, injection wells, or soil amendments. Some of the sites identified as active landfills in this report are waste treatment areas that are not permanently used for storing waste – for example, 5 sites are "processing" facilities such as green waste chipping and composting sites or sites where construction and demolition materials are processed before being transported elsewhere.	SWRCB and RWQCB with other state & local agencies such as CalRecycle, Counties, and Cities.
Landfill (active)	6		
Total	**982**		

Contaminants found in soil and groundwater in the ART project area include industrial solvents (such as acetone, benzene, and chlorinated solvents and their byproducts), acids, paint strippers, degreasers, caustic cleaners, pesticides, chromium and cyanide wastes, polychlorinated biphenyls (PCBs) and other chlorinated hydrocarbons, radium associated with dial painting and stripping, medical debris, unexploded ordnance, metals (e.g., lead, chromium, nickel), gasoline, diesel, and petroleum byproducts, and waste oils. Most of the contaminated lands sites are privately owned, although cities and municipalities often own closed landfills that are now used as parks and open space. The cleanup of contaminated lands is overseen by a number of agencies. The US Environmental Protection Agency (US EPA) is the lead regulatory agency for Superfund sites, and the Navy, DTSC, and the San Francisco Regional Water Quality Control Board (RWQCB) are also involved in the Alameda Point site. The State Water Resources Control Board (SWRCB), San Francisco RWQCB, and DTSC manage Site Cleanup Program sites, and UST sites are managed by the SWRCB, with the San Francisco RWQCB or DTSC often authorized with implementation of cleanup.

Most of the contaminated lands in the ART project area are at various stages of remediation, ranging from being under investigation to determine the risk to water quality and human and environmental health to active cleanup. Sites that have been remediated and closed – i.e., where contaminants have been fully removed – are not included in this analysis. Sites that have been remediated by leaving contaminants in place and containing them through capping or other methods are included in this report. This includes closed landfills, which, once they stop receiving waste, are meant to remain in place. Of the 21 landfills identified in this report, only one is actively receiving solid waste for permanent storage, while there are five active "processing" facilities. These sites receive waste such as construction and demolition materials or green waste, process it onsite, and then send it elsewhere. There are 15 closed solid waste storage sites, including a dredge disposal site, a steel company's disposal site, and many former "dumps" or landfills that existed prior to the passage of regulations requiring permits for such facilities. Many of these earlier, pre-regulation landfills are not lined; however, waste at closed Bay margin landfills is generally well isolated, due to the low permeability of the native deposits (Bay mud) underlying them. This means that even if a landfill cap is not watertight and surface water comes into contact with the buried waste, the resulting leachate should not be released into the groundwater at a significant rate. To guard against this possibility, however, groundwater and surface waters at the landfills are monitored regularly, and many landfills have leachate collection systems.

For the purposes of this assessment, the goal of contaminated lands management is to prevent the release and spread of the hazardous substances with which the land is contaminated. The release of hazardous substances occurs through four primary pathways: groundwater migration, surface water flow, soil exposure, and release to the air (vaporization). These pathways affect receptors indirectly, through contamination of drinking water and food chains, as well through direct exposure of human populations and sensitive ecosystems (US EPA, Hazard Ranking System). This assessment evaluates the vulnerability of contaminated lands with regard to how well current management can prevent the release and spread of contaminants in the face of sea level rise.

Exposure

Exposure is the extent to which an asset – such as a leaking UST, landfill, or Superfund site – experiences a specific climate change impact such as storm event flooding, tidal inundation, or elevated groundwater. This report analyzes exposure of the eight types of contaminated lands identified in the ART project area to two sea level rise projections and three Bay water levels. The two sea level rise projections, 16 inches (40 cm) and 55 inches (140 cm), correlate approximately to mid- and end-of-century. These projections were coupled with three Bay water levels: the highest average daily high tide represented by mean higher high water (MHHW), hereafter "high tide" or "daily high tide;" the 100-year extreme water level, also known as the 100-year stillwater elevation (100-year SWEL), hereafter "100-year storm" or "storm event;" and the 100-year extreme water level coupled with wind-driven waves, hereafter "storm event with wind waves" or "wind waves." These water levels were selected because they represent a reasonable range of potential Bay conditions that will affect flooding and inundation along the shoreline. For more information about sea level rise projections and Bay water levels evaluated see Chapters 1 and 2.

The exposure of contaminated sites was analyzed for a circular 164-foot (50-meter) diameter footprint centered on the point location of the site (see Appendix C). This approach was verified as being representative of the approximate footprint of most assets evaluated in this manner. The exposure of each type of contaminated lands to the daily high tide, storm event flooding, and wind waves was evaluated in a binary, i.e., yes versus no, analysis. Whether each site is within a disconnected low-lying area[2] was also evaluated and recorded as yes or no.

Table 2 shows the number of each type of site exposed. With 16 inches of sea level rise, only 14 of the 982 sites will be exposed to the new daily high tide, and 19 sites are in disconnected low-lying areas that could be exposed. Sixty sites will be exposed to storm event flooding, and 48 are in disconnected low-lying areas that could be exposed to this impact. The 60 sites exposed to storm event flooding will also be exposed to wind waves, and 345 additional sites will be exposed to wind waves only.

Many more sites will be exposed to the new Bay water levels with 55 inches of sea level rise. One hundred thirteen sites will be exposed to the new daily high tide, with an additional 18 sites in disconnected low-lying areas potentially exposed. Three hundred forty three sites will be exposed to storm event flooding, and eight sites in disconnected low-lying areas could be exposed to this impact. The 343 sites exposed to storm event flooding will also be exposed to wind waves, and 145 additional sites will be exposed to wind waves only.

[2] Disconnected low-lying areas are at the same elevation or are lower than an adjacent inundated area. Assets in these areas are not considered exposed because a topographic feature such as a railroad or road embankment should prevent inundation. However, they could be exposed if the protective feature fails. See Chapter 2 for a more detailed explanation.

Table 2. Number of contaminated lands sites exposed to the daily high tide and storm event flooding with 16 and 55 inches of sea level rise.

		16" SLR			55"SLR		
		Daily High Tide	Storm Event		Daily High Tide	Storm Event	
Type of Asset	**Total number of sites**	**Number exposed**	**Number exposed**	**Number exposed to wind waves only**	**Number exposed**	**Number exposed**	**Number exposed to wind waves only**
Superfund	2			2		1	1
Site Cleanup Program	303	7	17	77	34	85	41
Leaking UST	405	3	11	98	21	92	50
Military UST	43		4	35	8	32	7
Military Cleanup	96	1	18	64	28	73	12
DTSC	112	1	5	63	16	49	30
Landfill	21	2	5	6	6	11	4
Total	**982**	**14**	**60**	**345**	**113**	**343**	**145**

The majority of the exposed sites contain petroleum products such as gasoline, diesel, and waste oils, and many of the exposed sites have already contaminated the local groundwater, which is being remediated under the supervision of federal, state, and local agencies. At least one site contains PCBs, while several others contain industrial solvents and/or metals. Two of the exposed sites are former landfills that have been turned into parks – Point Emory Park and Oyster Bay Regional Park.

Sensitivity and Adaptive Capacity

The sensitivity and adaptive capacity of contaminated lands in the ART project area was assessed for three potential climate impacts that could occur due to sea level rise and storm events. The three climate impacts considered are:

- More frequent floods or floods that last longer due to storm events
- Permanent or frequent inundation by the daily high tide
- Elevated groundwater levels and saltwater intrusion

Sensitivity is the degree to which an asset or entire system (e.g., landfills, UST sites, or management capacity of DTSC, SWRCB, and the San Francisco RWQCB) would be physically or functionally impaired if exposed to a climate impact. Adaptive capacity is the ability for an asset or system to accommodate or adjust to a climate impact and maintain or quickly resume its primary function. The sensitivity of the contaminated lands varies by type of site, the contaminants present, their mobilization pathways, and the degree of remediation.

Across all categories of sites, the types of contaminants present affect sensitivity. Contaminants that are bound to sediments, such as PCBs, could be mobilized into the Bay or other areas if the sediments to which they are bound are disturbed and relocated, for example, due to wave action during storms. Other types of contaminants, such as solvents, are often present as soil gas and could go into solution if exposed to water – this could occur due to rising groundwater or infiltration of Bay water during high tides or storms. Another source of sensitivity common to all types of sites is the shortage of funding for cleanup. In some cases, the landowner cannot be located or is unable to pay for or participate in cleanup; while public funds may be available in such cases, additional agency intervention may be necessary, extending the timeline for cleanup.

Another source of sensitivity across the system is the proximity of the ART project area to seismic faults. Earthquakes could compromise the integrity of caps and liners, and could also cause liquefaction, which occurs when loose sediments are shaken and can result in widespread lateral displacement of the land surface. Rising groundwater increases the risk of liquefaction, which is already very high in the ART project area. Displacement of the ground due to liquefaction in a seismic event could compromise the stability of waste containment facilities, such as landfill caps or liners, caps over remediated sites, and slurry walls constructed to contain contaminants. Sensitivity to climate impacts for the different categories of contaminated lands is discussed below.

Leaking USTs tend to contaminate soil and groundwater in their vicinity. Therefore, they are sensitive to rising groundwater, since this impact could expose more groundwater to contaminants. Saltwater intrusion into groundwater could also corrode underground storage tanks (Titus, 2009) and cause additional leaking. USTs are less likely to be sensitive to storm-related flooding unless floodwaters are very high-energy and scour contaminated soils, exposing and possibly moving the tank. Floodwater that remains for a long time period could infiltrate through the soil or enter the tank and become contaminated, or cause empty tanks to "float" and pop out of the ground. Tidal inundation could pose more of a problem, due to the frequency and duration of exposure, which could result in greater likelihood of contact with contaminated soils and tank contents, leaching through contaminants to groundwater below, or causing empty tanks to float.

One source of adaptive capacity for some leaking USTs is the possibility of removing them, which would at least prevent additional contamination of the area. Further remediation would need to take place to remove contaminants that have already released. One approach for some types of contaminants, such as solvents, is to treat contaminated groundwater in situ. Where this is an option, it contributes to adaptive capacity, and these techniques may be increasingly necessary as groundwater tables rise and more groundwater interacts with contaminants. Monitoring tanks so that leaks are detected early also adds to adaptive capacity.

Site Cleanup Program and DTSC sites have historically been remediated in two ways: removal and in-place remediation. Sites where contaminants have been completely removed and the site is considered closed are not included in this report. Some sites are remediated in place because there is nowhere to take the material, or it is deemed to be a less environmentally harmful approach – for example, trucking loads of contaminated materials contributes to GHG emissions, and digging up and transporting contaminated soil could create new opportunities for exposure. Most sites that have been remediated in place are covered with one to three feet of clean soil under a cap of concrete or other material (sometimes in the form of a road or building). While this method is intended to contain contaminants, such sites are sensitive to flooding and rising groundwater. For example, water-soluble substances, such as solvents, could become mobilized in floodwaters in sites with compromised caps that do not prevent the infiltration of Bay water, and rising groundwater could also become contaminated with water-soluble substances.

Sites where contaminants can be completely removed have greater adaptive capacity than those that must have in-place remediation. Adaptive capacity also comes from regulatory requirements and procedures. For example, upon discovery of a contaminated site, DTSC and RWQCB coordinate to determine which agency is most appropriate to lead the cleanup. The lead agency then conducts a preliminary environmental assessment, carries out a remedial investigation to determine the extent of contamination, and develops a cleanup plan. This process can take years from initiation to the implementation of cleanup, and the cleanup itself can take many years, depending on the nature and extent of the contamination, cooperation of site owner(s), and resources available. While the long timeframe adds to sensitivity, the thorough documentation and remediation planning contribute to adaptive capacity. DTSC policy also requires periodic monitoring of sites where contaminated materials have been remediated in place, and requires that such sites be checked after a disaster such as an earthquake or a flood to ensure that the containment method is still operating as intended.

Landfills could be sensitive to sea level rise, depending on the type and location of the site. Closed permanent storage facilities, like the remediated sites discussed above, are generally capped by an impermeable or low permeability layer, such as clay, and underlain by the native geologic material, which for landfills on the Bay margin is a type of clay called Bay Mud (Figure 2). The caps are designed to prevent the vertical migration of water from above the landfill, into and through the waste, and down to the groundwater table. However, tidal inundation or storm event flooding could contribute to the creation of leachate where caps are not watertight. Leachate production could also occur if rising groundwater migrates into the waste, which would necessitate greater leachate removal at some sites where it is already necessary, or the installation of a leachate collection system at sites where it has previously not been necessary.

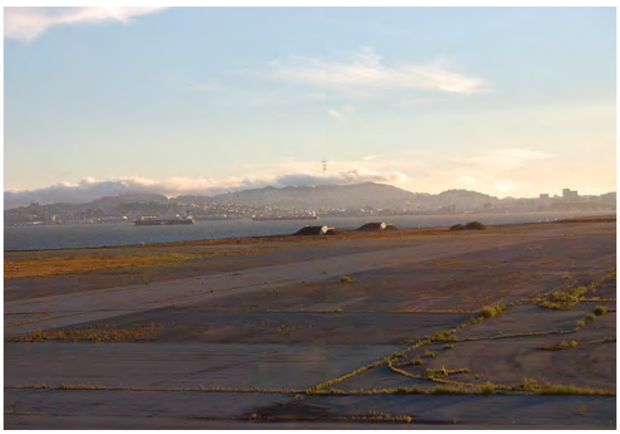
Figure 2. Oyster Bay Regional Shoreline is a closed landfill that has been capped and turned into a park.

Swiftly flowing floodwaters in a storm event could scour the sides of landfills and expose buried wastes. Older landfills may be particularly sensitive to climate impacts, as some were constructed, filled, and capped prior to regulations regarding linings, caps, leachate collection, and other design principles. However, they are closely monitored and managers are required to take corrective action if there is a threat to water quality or human or environmental health. While waste processing sites should not be sensitive to tidal inundation and rising groundwater because materials can be moved from these facilities, they could be sensitive to storm event flooding if there is insufficient time to remove materials.

Adaptive capacity derives from the guidelines and rules regulating the management of contaminated lands. For example, the SWRCB issues Waste Discharge Requirements (WDRs) that guide site management practices for landfills. WDRs are periodically updated, which gives the SWRCB the ability to identify vulnerabilities and modify management plans over time. As part of these updates, the SWRCB is now requiring site owners to plan for sea level rise. While WDRs may only be updated every 5-15 years for any given site, potential sea level rise effects, among other issues, are evaluated every five years. If necessary, a similar clause could be included in Cleanup and Abatement Orders, the primary regulatory tool for cleanup cases.

Also contributing to adaptive capacity in the case of landfills is the requirement for immediate remediation if a release of contaminants is discovered. Because each site is already characterized – that is, regulators know the contents of the landfill and are aware of nearby sensitive receptors – regulators and owners know the risks associated with a release and should therefore be well equipped to take action. Landfill owners are also required by law to maintain stable slopes on landfills, which contribute to adaptive capacity with regard to erosion potential. Management practices such as monitoring groundwater, pumping leachate, building and maintaining levees around sites (such as landfills in or directly adjacent to the Bay), using stormwater ditches to route surface water, and developing disaster response plans all contribute to adaptive capacity.

Figure 3. Alameda Point Superfund site. (Source: Telstar Logistics', Flickr Commons)



The Superfund sites in the ART project area contain most of the types of sites discussed above, including landfills, USTs, and cleanup sites, and thus have the same types of sensitivity and adaptive capacity. Their size, complexity, and the variety of contaminants present, however, make them particularly sensitive. For example, in addition to multiple UST sites and landfills, Alameda Point has a plume of contaminated groundwater and unexploded ordnance (Figure 3). While the federal funding and EPA support that comes with a Superfund designation should contribute to adaptive capacity, Superfund has a backlog of sites to clean up and is woefully underfunded (U.S. PIRG, 2005).[3]

In addition to the sensitivity of each contaminated lands site, the system of contaminated lands is sensitive to sea level rise. One form of sensitivity is related to the concentration of each contaminant in the environment, which determines the extent of the consequences. The exposure and release of contaminants from multiple sites could have greater impacts than isolated releases. For example, in the case of PCBs, should multiple sites release this contaminant into the Bay, it could affect overall concentrations to a greater degree than a single release. Another sensitivity of the system is the challenge of responding to multiple exposures; should asset owners and managers become overwhelmed, for example, in preventing releases from their sites in the event of a large storm, the system as a whole would be vulnerable. Likewise, coordinating among all of the agencies responsible for contaminated lands if there is a large event could prove challenging (See Box on Hurricane Katrina).

The sensitivities and sources of adaptive capacity discussed in this section are specific to the types of contaminated lands identified in this report. However, there are other types of contaminated lands that are not considered here, such as residential properties with lead contamination from old paint that has flaked off onto the grounds. Such sites pose additional challenges, as they are undocumented, have not been remediated, and are likely to be present on the land surface, where mobilization could more easily occur than documented sites under remediation.

[3] While this is a problem for many Superfund sites, including the AMCO site, the cleanup of Alameda Point is funded by the Navy, so the Superfund budget is less of a concern in this case.

Hurricane Katrina and Contaminated Lands

Recent events demonstrate some of the challenges posed by the flooding of contaminated lands and provide examples of adaptive capacity and governance issues. Hurricane Katrina passed over 18 Superfund National Priority List sites and more than 400 industrial facilities that store or manage hazardous materials, and caused the release of over 7 million gallons of oil in Louisiana and Mississippi (US EPA, 2006). The US EPA sampled Superfund sites, sediments, and drinking water during and after the flood and coordinated with state and local agencies to share testing data and communicate with the public – for example, issuing temporary boil orders where drinking water was unsafe.

In a summary of the incident, the agency states that tests of floodwaters and Lake Pontchartrain did not indicate a higher level of contaminants post-flood than existed before, and they determined that contaminants did not pose a human health risk in most areas. Likewise, testing after the floodwaters receded of sediments spread throughout the city did not indicate a general increased risk from contaminants (Reible et al., 2006). However, certain areas of the city near specific sites or events, such as the failure and spill of the Murphy Oil crude oil tank and the Agriculture Street Landfill (a closed Superfund site), tested above acceptable levels for certain contaminants including Polycyclic Aromatic Hydrocarbons (PAHs), which are carcinogens, and arsenic (NRDC, 2005; US EPA, 2008). Katrina highlights the sensitivity of contaminated lands to flooding – even those that have been cleaned up – as well as the potential consequences to human health and the environment when contaminants are released.

Consequences

The potential consequences of the climate impacts on contaminated lands are considered for the ART project area. Consequences are the magnitude of the economic, social, environmental, and governance effects if an impact occurs. Factors that inform the magnitude of the potential consequences include the severity of the impact on Operations and Maintenance or capital improvement costs, the size and demographics of the population affected, the types of natural resources affected, and the type, extent, and severity of the effects on humans and the environment.

Economy

There are potential direct and indirect economic consequences related to the exposure of contaminated land to climate impacts. Direct consequences include the costs of containment efforts, such as sandbagging, digging trenches, and pumping leachate, and cleanup of damaged property. Indirect economic consequences include losses if the contaminants were to affect an industry such as fisheries or tourism. If human health is affected, productivity losses, increased health care costs, or liability claims could also occur. A longer-term economic impact could occur if contaminants are redistributed onto new sites, reducing the availability of productive, usable land and increasing the number of sites requiring cleanup.

Society

Much of the contaminated land in the ART project area contains materials that are harmful to human health. The actual health consequences of a release of contaminants would depend on the substances released and the proximity of the sites to sensitive receptors, such as residential areas, schools, hospitals, and housing for the elderly. It also depends on the mode of contamination. For example, lead – one of the contaminants found in the ART project area – is commonly ingested by children playing in soils that contain lead-based paint chips; the children unknowingly ingest it, which can cause developmental and other health problems. Lead in contaminated sediment that is redistributed by tidal action or storm events associated with sea level rise could increase the potential for exposure through this same pathway. PCBs, on the other hand, are more of a concern for human health if they are suspended in the water column and consumed by fish (and then by people), since they reach high concentrations in wildlife at the top of the food chain where they can cause developmental abnormalities, growth suppression, endocrine disruption, impairment of immune system function, and cancer. Structures built over a site contaminated with solvents can experience indoor air problems when contaminants are dissolved in groundwater. Contaminants that come into contact with groundwater would pose an additional threat to human health if the water were used for drinking; as mentioned above, many leaking USTs in the ART project area have already contaminated the groundwater near them, but this water is not used for drinking at this point and it is undergoing remediation. Unexploded ordnance at military cleanup sites poses an entirely different set of consequences for society – namely, that its redistribution could result in the undocumented presence of dangerous explosive material in unlikely places.

Environment

As is the case for human health, many of the materials contained in contaminated lands are also hazardous to the environment. Section 303(d) of the Federal Clean Water Act requires that states develop a list of water bodies that do not meet water quality standards, establish priority rankings for waters on the list and develop action plans to improve water quality. For San Francisco Bay, the RWQCB proposes a list of primary pollutants or stressors every two years. Several of the pollutants found in contaminated lands in the ART project area, such as PCBs, nickel, lead, chromium, cyanide, and pesticides are on the 2010 303(d) list for San Francisco Bay. Some of these pollutants, such as PCBs, affect the health of wildlife just as they do people.

Governance

Many contaminated lands sites are privately owned, although municipalities own some sites, such as many of the landfills. A number of entities are responsible for directing cleanups, developing and enforcing operational requirements, and inspecting and monitoring sites. Multiple agencies may have authority over the same site in some cases, especially if several types of contaminant sources are present on one site. Such joint jurisdiction is handled through contracts. The current complex system of site management could cause delays or other inefficiencies in developing strategies and priorities, or responding to problems; on the other hand, the large number of agencies regulating contaminated lands and their cleanup, each from a different perspective, should help to catch any problems that may arise, which could ultimately create a more resilient system. However, with current funding levels of clean up efforts insufficient to keep pace with newly identified sites, if sea level rise impacts mobilize contaminants along pathways to sensitive receptors, it is possible that exposure rates to humans, wildlife and habitats could increase.

Key Findings

There are nearly 1,000 contaminated lands sites in the ART project area. Most are not exposed to the daily high tide or storm events with 16 inches of sea level rise, although approximately one third are exposed to wind waves. Even with 55 inches of sea level rise, the majority of contaminated lands are not exposed to the daily high tide; 261, or approximately 25%, are exposed to storm events, with an additional 163 exposed to wind waves only. The most common sites in the ART project area are leaking USTs and Site Cleanup Program sites; these are also the sites most commonly exposed to sea level rise.

Different types of contaminated lands are vulnerable to sea level rise in different ways. Sites contaminated with solvents, for example, are sensitive to rising groundwater because solvents can go into solution in groundwater and spread underground and/or cause air quality problems in buildings constructed on top of the site. Sites with PCBs, on the other hand, may be more sensitive to storm event flooding because PCBs bind to sediment; if floodwaters cause erosion of contaminated sediments, PCBs could be carried to the Bay, where they are already a problem for wildlife and people who consume fish caught in the Bay.

Where contaminants can be removed, vulnerability is lower. Sites with contaminants that cannot be removed due to technical challenges, environmental risks, or funding issues, must be remediated in place. This involves caps, liners, pumps, in situ groundwater treatment, and other measures to ensure that contaminants are contained. These sites are subject to regular monitoring as well as special checks after natural disasters such as floods and earthquakes. More frequent flooding and rising groundwater could result in the need for more checks and improved containment measures.

Because most contaminated land sites are privately owned, the pace of cleanup depends in part on being able to locate property owners, and on the availability of funding either from property owners or public sources. Regulatory agencies mandate certain practices – such as the SWRCB's Waste Discharge Requirements (WDRs) requiring site owners to plan for sea level rise – that contribute to adaptive capacity, and they may prioritize cleanup among the sites under their purview. However, there is no single database that the public can use to track and understand the condition of contaminated sites that may be vulnerable to sea level rise and other risks.

While the majority of contaminated lands are not exposed to sea level rise, the sheer number of sites in the ART project area means that the small percentage adds up to a large number of sites that are exposed. As a category, contaminated lands have moderate vulnerability. While the absolute number of sites exposed to sea level rise is fairly high, most are not exposed to 16 inches of sea level rise. The existence of sites that cannot be removed makes the category fairly sensitive, but technology such as pumping and in situ treatment contributes to adaptive capacity. The network of agencies involved contributes both to sensitivity and adaptive capacity; while having more "eyes on the ground" can help prevent sites from slipping through the cracks, it could create complications in coordinating cleanup, and the many agencies involved, combined with the fact that most sites are privately owned, means that there is no centralized entity positioned to prioritize cleanup across all types of sites based on risks from sea level rise.

References

Natural Resources Defense Council (NRDC). 2005. Sampling Results: Bywater/Marigny Including Agriculture Street Landfill.
http://www.nrdc.org/health/effects/katrinadata/bywater.asp#sediment.

Reible, D.D., C.N. Haas, J.H. Pardue, and W.J. Walsh. 2006. Toxic and Contaminant Concerns Generated by Hurricane Katrina. *The Bridge*, Spring 2006.

Titus, J.G. and M. Craghan. 2009. Shore Protection and Retreat. In: J.G. Titus (coordinating lead author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors). *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region.* U.S. Environmental Protection Agency, Washington DC, pp. 87-103.

US Environmental Protection Agency (US EPA). 2006. EPA Report No. 2006-P-00023. Lessons Learned: EPA's Response to Hurricane Katrina.

US Environmental Protection Agency (US EPA). 2008. Response to 2005 Hurricanes – Murphy Oil Spill. http://www.epa.gov/katrina/testresults/murphy/index.html.

U.S. Public Interest Research Group (PIRG) Education Fund. 2005. Empty Pockets: Facing Hurricane Katrina's Cleanup with a Bankrupt Superfund.
https://pincdn.s3.amazonaws.com/assets/.../emptypockets.pdf.

Chapter 15. Hazardous Material Sites

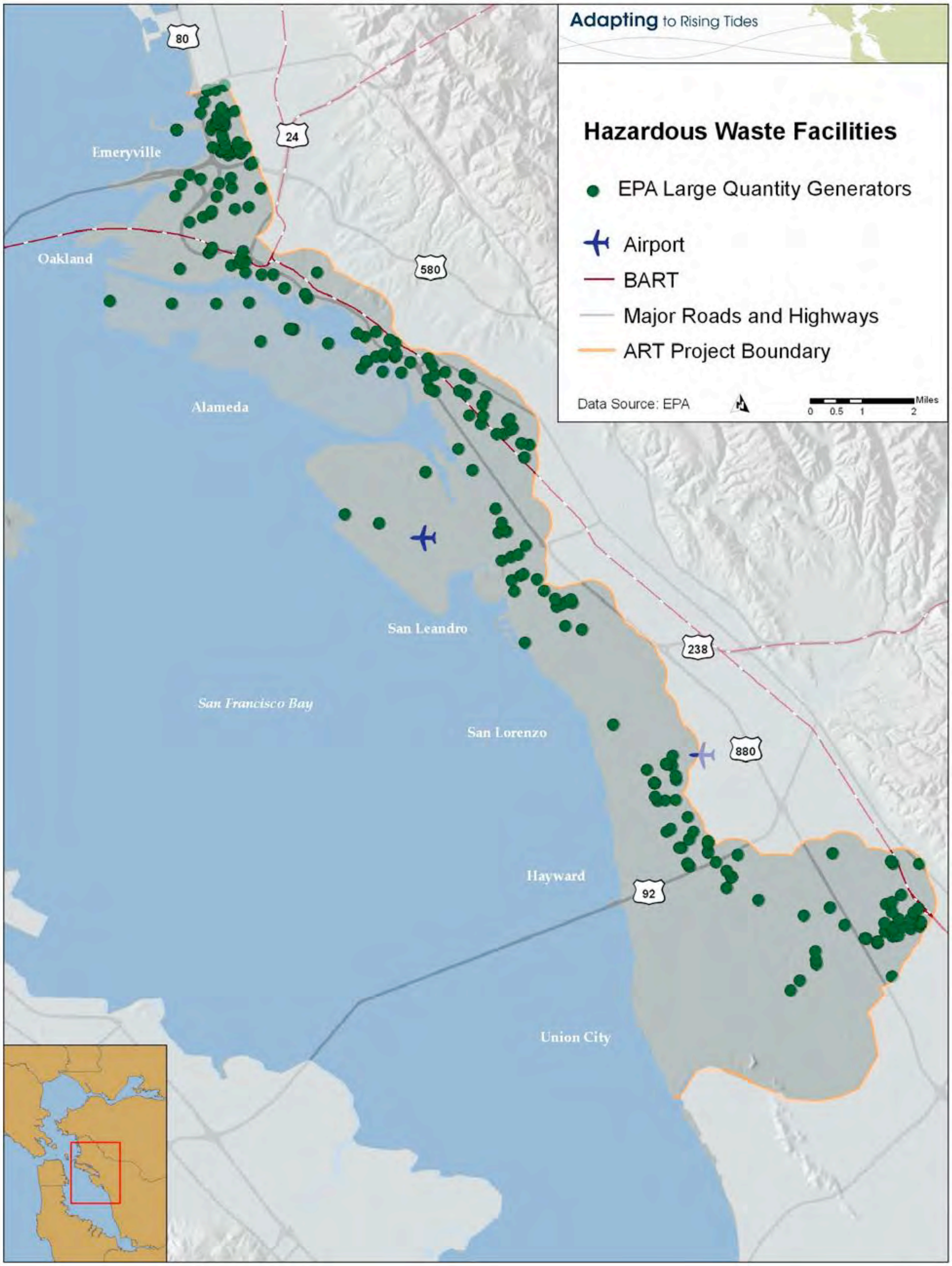
Hazardous materials are substances that pose a risk to human health and the environment. More precisely, a material or waste product is considered hazardous if it appears on certain lists prepared by a federal, state, or local agency, or if it has characteristics defined as hazardous by such an agency. Different levels of government may have different definitions of hazardous materials – for example, California's definition is more stringent than the federal definition. A substance may also be considered hazardous based on chemical and physical properties such as toxicity, ignitability, corrosivity, and reactivity (California Code of Regulations). Hazardous materials can be liquid, solid, sludge, or gas; they may be the byproducts of industrial/manufacturing operations or discarded commercial products such as pesticides and cleaning solvents. The exposure analysis in this report focuses on facilities that generate hazardous waste[1], as defined and tracked by the US EPA.

The ART project area contains a wide variety of hazardous waste sites, ranging from pharmaceutical and other bioscience laboratories to metal processing and other manufacturing facilities (Figure 1). Other sites, such as gas stations, use or store petroleum products, and others are associated with transportation activities, such as Caltrans maintenance and transit operators' facilities. As this partial list indicates, hazardous wastes and their modes of generation and storage vary widely. A pharmaceutical company or medical facility, for example, may store waste in small plastic containers (less than 5 gallons), while a petroleum-associated business could store materials in 55-gallon drums or even larger underground or aboveground storage tanks. Hazardous waste could be stored inside buildings or outdoors, depending on the type of substance and local regulations. Union City's building and fire codes, for example, do not allow the outdoor storage of hazardous waste.

This report addresses hazardous materials primarily from the perspective of emergency response. This is because the most significant impact of sea level rise and storm events on hazardous materials sites will be during a flood emergency, and the vulnerability and risk for the surrounding community will depend largely on responders' ability to contain or manage any hazardous materials that are exposed to flooding. Hazardous materials and hazardous waste sites that are affected by the new daily high tide or rising groundwater would presumably be relocated, as their main function would be difficult to maintain with daily inundation or problems with high groundwater. However, many of these sites, even if they moved their point of operations, could leave behind hazardous waste, either above ground or in the form of contaminated land; the latter is addressed in a separate chapter. Other types of facilities that contain hazardous materials, such as wastewater treatment plants, will be very difficult to move.

[1] The terms "hazardous waste" and "hazardous material" do not refer to the same thing; while all hazardous wastes are hazardous materials, not all hazardous materials are hazardous wastes. However, geographically specific data on hazardous materials sites in the ART project area is not available, while a database of hazardous waste sites is. Therefore, while the discussion of sensitivity, adaptive capacity, and consequences is intended to apply broadly to all types of hazardous materials sites, the exposure analysis and the federal classifications listed in this section apply only to hazardous waste facilities.

Figure 1. Hazardous waste facilities in the ART project area.



The primary federal law that regulates hazardous waste is the Resource Conservation and Recovery Act (RCRA). RCRA applies to the generation, transportation, storage, treatment, and disposal of hazardous waste through its regulation of the following types of facilities (US EPA Hazardous Waste Website):

- "Generators"—individuals or facilities whose processes or actions lead to the creation of hazardous waste.
  - Large Quantity Generators (LQGs) generate 1,000 kilograms[2] per month or more of hazardous waste, or more than 1 kilogram per month of acutely hazardous waste.
  - Small Quantity Generators (SQG) generate more than 100 kilograms, but less than 1,000 kilograms, of hazardous waste per month.
  - Conditionally Exempt SQGs generate 100 kilograms or less per month of hazardous waste, or 1 kilogram or less per month of acutely hazardous waste.
- "Treatment"—facilities that change the physical, chemical, or biological characteristics of a waste to minimize its threat to the public and the environment. These facilities are referred to as treatment, storage, and disposal (TSD) sites.
- "Transporters"—facilities or entities that move waste from one site to another via roadways, rail, water, or air.

RCRA provides guidelines for federal waste management, directs the US Environmental Protection Agency (US EPA) to craft regulations to implement the law, and allows for the US EPA and state and local partners to enforce the regulations. In California, the following State agencies participate directly in hazardous waste management: California Environmental Protection Agency (Cal EPA); the Department of Toxic Substance control (DTSC); the State Water Resources Control Board (SWRCB); the California Emergency Management Agency (Cal EMA); and the State Fire Marshal. These agencies provide support and oversight to the city and county agencies, known as Certified Unified Program Agencies (CUPAs), which are authorized by the State to carry out the Hazardous Materials and Hazardous Waste Program[3] (Unified Program) (See Figure 2). The Unified Program consolidates six required State programs that deal with permitting and managing hazardous materials:

- **Hazardous Materials Release Response Plan and Inventory.** This program requires businesses that handle hazardous materials above 55 gallons, 500 pounds, or 200 cubic feet of gas to develop a business plan which inventories their hazardous materials, create a map, develop an emergency response plan, and implement a training program for employees. CalEMA provides support for this program.
- **California Accidental Release Program (CalARP).** This program aims to prevent the release of substances that can cause harm to the public and the environment. CalARP requires the development of a Risk Management Plan (RMP). CalEMA provides support for this program.
- **Underground Storage Tank Program (UST).** A UST is a tank and connected pipes, used to store hazardous substances, which is beneath the surface of the ground. The purpose of the UST Program is to protect the public and the environment from releases of petroleum and other hazardous substances from tanks. The four program elements are leak prevention, cleanup, enforcement, and tank tester licensing. The SWRCB provides technical assistance and evaluation for the UST program.

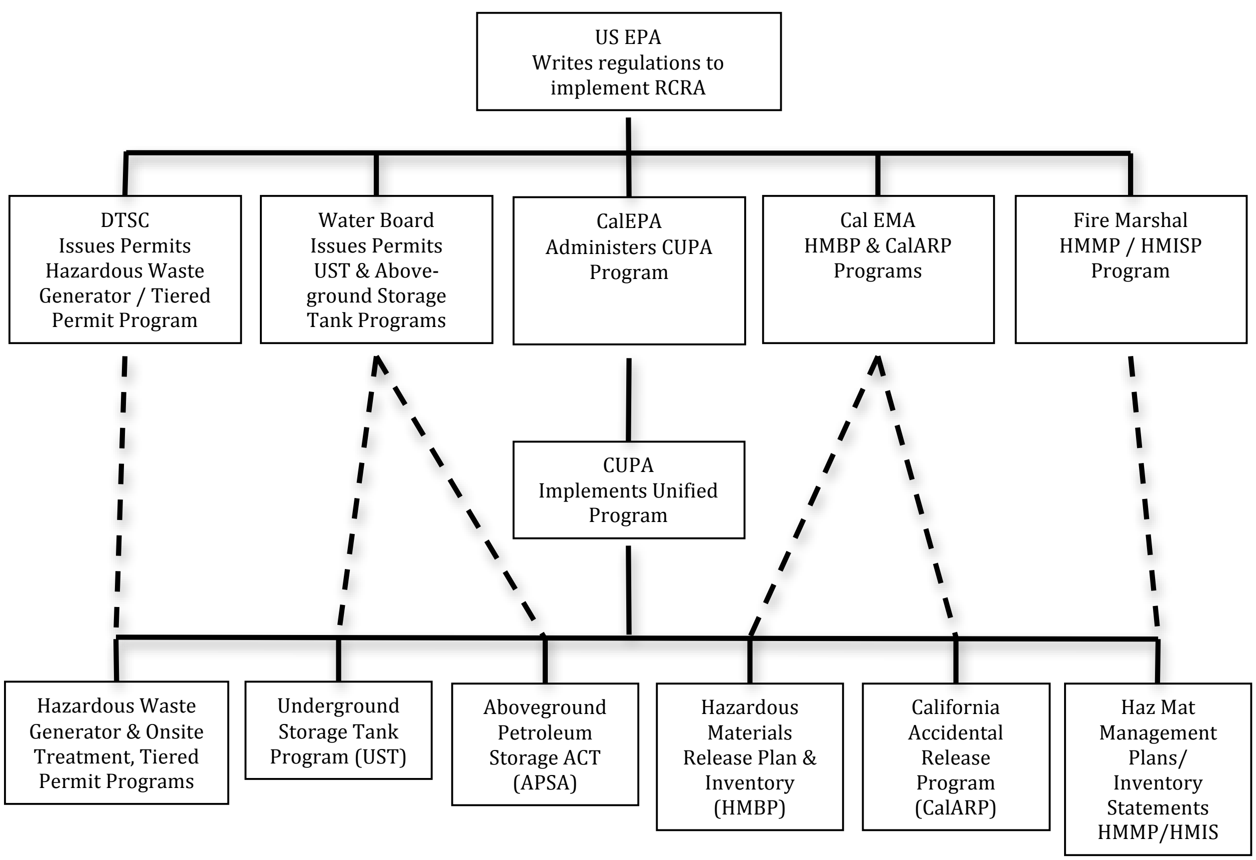
---

[2] 1 kilogram is approximately 2.2 pounds.

[3] While the RCRA database used in this report's exposure analysis only includes hazardous wastes, CUPAs oversee programs for hazardous waste and non-waste hazardous materials. CUPAs are therefore sources of information about hazardous materials sites in their jurisdiction; however, a complete, geo-referenced dataset of the hazardous materials sites was not available from the CUPAs in the ART project area.

- **Aboveground Petroleum Storage Act.** An aboveground storage tank is a tank that stores petroleum above ground. The act requires CUPA staff to inspect tanks with more than 55 gallons of petroleum at least once every three years. In addition, the act requires the owner of any tank with over 1,320 gallons of petroleum to prepare and implement a Spill Prevention Plan consistent with federal regulations. The SWRCB provides technical assistance and evaluation for the aboveground storage tank program.
- **Hazardous Waste Generator and Onsite Hazardous Waste Treatment / Tiered Permitting Programs.** This program establishes a five-tiered program for authorizing hazardous waste treatment at businesses that are required to have a state permit or authorization to do so. The tiers match the burden of regulation to the amount of risk in the hazardous waste activity. DTSC provides technical assistance and evaluation for these programs.
- **California Fire Code: Hazardous Materials Management Plans/ Hazardous Materials Inventory Statements (HMMP/HMIS).** The Plans are similar to the Business Plans and to the extent possible they have been merged. The main goal of the statute and regulations is to increase communication, coordination, and consistency/consolidation. The Office of the State Fire Marshal provides support for this program.

Figure 2. Federal, State, and Local Hazardous Materials Regulatory Agencies.



The purpose of the CUPAs and the Unified Program is to consolidate, coordinate, and make consistent the administrative requirements, permits, inspections, and enforcement activities of the six environmental and emergency response programs. Since the Unified Program was instituted, the Secretary of Cal EPA has certified 83 CUPAs, which carry out the responsibilities previously handled by approximately 1,300 state and local agencies. Cal EPA reviews the CUPAs annually to ensure that they are properly carrying out the Unified Program, and CUPA leads receive Hazardous Waste Operations and Emergency Response (HAZWOPER) and other relevant training.

The Unified Program helps agencies prevent and respond to an accidental release of hazardous materials. Some program elements provide guidance on the proper handling and storage of materials – to prevent release – while others help responders in the event of a release. For example, the HMBP requires business to keep an inventory on the types and quantities of hazardous materials present, as well as to develop a plan for how to contain the materials in the event of an accident. In addition, each CUPA must prepare and routinely update an Area Plan, which is a contingency plan for agencies that respond to emergencies involving the release of hazardous materials. These documents help guide responders in any emergency that may affect hazardous materials. Fire departments, even where they are not the authorized CUPA, are expected to be familiar with the hazardous materials sites in their jurisdiction, and may be the first responder to an incident involving hazardous materials.

There are five CUPAs in the ART project area:

- Alameda County Environmental Health Department covers the City of Alameda, Emeryville, and San Lorenzo, as well as unincorporated areas and several other cities outside of the ART project area
- Hayward City Fire Department
- Oakland City Fire Department
- City of San Leandro Environmental Services Section
- Union City Environmental Program Division

These CUPAs work with agencies as directed in the Statewide Emergency Response System (SEMS), which provides an organizational framework and guidance for operations at each level of the state's emergency management system. CUPA staff is available 24 hours a day, 7 days a week, to provide information to responders in the event of an emergency, and fire departments have access to their files. If the magnitude of a release and any associated problems are beyond the capacity of the CUPA and other local agencies to respond, SEMS and other frameworks and agreements describe how other agencies at a countywide, regional, state, and even federal level can contribute to resolving the problem. For example, DTSC has an Emergency Response Program (ERP) with officers on duty around the clock to respond to hazardous material releases that pose an acute threat to public health or the environment (DTSC, 2010).

One component of SEMS is the Master Mutual Aid Agreement, which lays out the policies and procedures for sharing resources in the event of an incident beyond local agencies' capacity. The State is divided into Operational Areas (counties) and six Mutual Aid Regions. The ART project area is in Region II, which covers the coastline from the border with Oregon to Monterey County. In the event of an emergency, local agencies may request the assistance of the County and other cities in the County, then other Operational Areas in the region, and then the State. If out-of-state aid is necessary, Cal EMA coordinates the response. Resource sharing across jurisdictional boundaries is quite common, and may not necessarily follow a strict protocol; for example, if an emergency response requires equipment that a city doesn't own, they may call a neighboring jurisdiction to borrow the equipment – this is more efficient then, for example, every city owning a backhoe. However, it could cause problems if a large event occurs and every city needs a backhoe or other equipment that is normally shared.

Another element of the emergency response system is the California Hazardous Materials and Oil Emergency Function (CA-HMO EF-10), an annex to the State of California Emergency Plan (SEP), which "provides coordination and support to actual or potential discharges and/or uncontrolled release of oil or hazardous materials to save lives, protect health and safety, protect property, and preserve the environment when activated." EF-10 can be activated when a hazardous material incident will have a significant impact or involve multiple agencies, mutual aid regions, a wide geographic area, multiple population centers, or multiple human and environmental targets. Cal EPA is the authorized lead agency for EF-10, although many other agencies may be involved as a primary agency[4] or supporting agency.[5] The location of the release and what is affected – such as the coastal zone, roadways, or other areas – determines which agency serves as the primary. The duties of each agency are defined in Administrative Orders, and each agency must prepare an Emergency Response Plan consistent with its Administrative Orders, which is reviewed and approved by Cal EMA.

Exposure

Exposure is the extent to which an asset, such as a hazardous waste site, experiences a specific climate change impact such as storm event flooding, tidal inundation, or elevated groundwater. This report analyzes the exposure of hazardous materials in the ART project area to two sea level rise projections and three Bay water levels. The two sea level rise projections, 16 inches (40 cm) and 55 inches (140 cm), correlate approximately to mid- and end-of-century. These projections were coupled with three Bay water levels: the highest average daily high tide represented by mean higher high water (MHHW), hereafter "high tide" or "daily high tide;" the 100-year extreme water level, also known as the 100-year stillwater elevation (100-year SWEL), hereafter "100-year storm" or "storm event;" and the 100-year extreme water level coupled with wind-driven waves, hereafter "storm event with wind waves" or "wind waves." These water levels were selected because they represent a reasonable range of potential Bay conditions that will affect flooding and inundation along the shoreline. For more information about sea level rise projections and Bay water levels evaluated see Chapters 1 and 2.

An exposure analysis was conducted for hazardous waste sites found in the EPA's online database of RCRA sites[6]. The exposure of the sites was determined within a circular 164-foot

[4] Primary agencies have jurisdiction to respond to a release. The following agencies may serve as primary agency: Air Resources Board (ARB); California Highway Patrol (CHP); Department of Fish and Game (DFG), Office of Spill Prevention and Response (OSPR); Department of Pesticide Regulation (DPR); Department of Toxic Substances Control (DTSC); State Water Resources Control Board (SWRCB), Regional Water Quality Control Board (RWQCB); Department of Resource Recovery & Recycling (DRRR); Department of Transportation (CalTrans); Office of Environmental Health Hazard Assessment (OEHHA); and, California Department of Public Health, Radiological Health Branch (CDPH/RHB).

[5] Supporting agencies provide technical, policy, and subject matter expertise, and are generally requested by the primary agency, although they may also have jurisdictional oversight. The following agencies may serve as supporting agencies: Attorney General's Office (AG), Department of Justice (DoJ); Bay Conservation & Development Commission (BCDC); Board of Governors, California Community Colleges; California Coastal Commission; California Conservation Corps (CCC); California Department of Public Health (CDPH), Office of Emergency Preparedness; California Energy Commission (CEC); Department of Conservation, Division of Oil, Gas & Geothermal Resources (DOGGR); Department of Food and Agriculture (CDFA); Department of Forestry and Fire Protection (CDF); Department of Housing and Community Development; Department of Industrial Relations (DIR/CAL OSHA); Department of General Services (DGS); Department of Parks & Recreation (DPRec); State and Consumer Services Agency; State Lands Commission (SLC); Public Utilities Commission (PUC)/Rail Operations Safety Branch; and Military Department, California National Guard (CNG).

[6] The EPA online database, Envirofacts (http://www.epa.gov/enviro/facts/rcrainfo/search.html), contains environmental data for many different types of facilities and substances that could pose a threat to the environment. The RCRA sites included in this database, and thus in this exposure analysis, were generators of hazardous waste – both LQGs and SQGs. The exposure analysis was conducted based on facilities in the database as of 2011; however, it is possible that this list is out of date, as facilities are responsible for removing themselves from the database if they go out of business or cease producing hazardous waste. Thus, the exposure analysis could overstate the number of sites exposed to climate change impacts. On the other hand, because the database only contains hazardous **waste** generators, the

(50-meter) diameter footprint centered on the point location of the station (see Appendix C). This approach was verified as being representative of the approximate footprint of most assets evaluated in this manner. The exposure of LQG and SQG sites to the daily high tide, storm event flooding, and wind waves was evaluated in a binary, i.e., yes versus no, analysis. Whether each site is within a disconnected low-lying area[7] was also evaluated.

There are a total of 100 LQGs and 52 SQGs in the ART project area, concentrated largely in Oakland and Hayward, which have their own CUPAs, and Emeryville, which is regulated by the Alameda County CUPA. Table 1 shows the number of hazardous waste generators in the ART project area. Additional types of hazardous waste (and hazardous materials) facilities, such as transporters, were not included in the exposure analysis because they were not in the database. Further analysis on which roads, highways, and rail lines are used to transport hazardous waste and materials, and what types of protocols exist to prevent release in the event of flooding, will be useful in advancing understanding of vulnerability in the region.

Table 1. Hazardous waste generator sites in ART project area, by city.

City	LQG	SQG	Total
Alameda	12	2	14
Emeryville	26	6	32
Hayward	52	15	67
Oakland	51	15	66
San Leandro	6	17	23
Union City	2	4	6
Total	**100**	**52**	**152**

Table 2 shows the number of LQG and SQG sites in each city that are exposed to sea level rise impacts with 16 and 55 inches of sea level rise. With 16 inches of sea level rise, only one site – an LQG in Oakland – will be directly exposed to the daily high tide, although two LQG sites are in disconnected low-lying areas that could be exposed to tidal inundation. 13 sites (nine LQGs and four SQGs) are exposed to flooding from a storm event, and seven LQG sites are in disconnected low-lying areas that could be exposed to this impact. An additional 54 sites (44 LQGs and ten SQGs) are exposed only to wind waves. With 55 inches of sea level rise, 31 sites (23 LQGs and eight SQGs) are exposed to the daily high tide, and two LQG sites are in disconnected low-lying areas that could be exposed. 68 sites (53 LQGs and 15 SQGs) are exposed to flooding in a 100-year storm event, and an additional 26 (20 LQGs and six SQGs) are exposed only to wind waves.

number of hazardous **materials** sites is much larger. That is, while all hazardous waste sites are hazardous materials sites, there could be many facilities that contain hazardous materials that do not generate enough hazardous waste to qualify as an LQG or SQG; likewise, an SQG could have far more hazardous materials on site than is reflected by SQG status. A deeper review, such as those conducted for some of the other asset categories addressed in this report, should consult each CUPA or local fire department for the most inclusive, precise, and up-to-date information.

[7] Disconnected low-lying areas are at the same elevation or are lower than an adjacent inundated area. Assets in these areas are not considered exposed because a topographic feature such as a railroad or road embankment should prevent inundation. However, they could be exposed if the protective feature fails. See Chapter 2 for a more detailed explanation.

Table 2. Number of hazardous waste generators exposed to the daily high tide and storm event flooding with 16 and 55 inches of sea level rise, by city.

	16" SLR			55" SLR		
	Daily high tide	Storm Event		Daily high tide	Storm Event	
City	Number exposed	Number exposed	Number exposed to wind waves only	Number exposed	Number exposed	Number exposed to wind waves only
Alameda						
LQG		3	6	5	9	3
SQG				1	1	
Emeryville						
LQG			7	1	7	5
SQG			1		1	2
Hayward						
LQG		1	13	5	14	5
SQG			1		1	5
Oakland						
LQG	1	3	16	10	19	4
SQG			4	3	4	3
San Leandro						
LQG		1	2	1	3	3
SQG		2	2	3	4	
Union City						
LQG				1	1	
SQG		2	2	2	4	
Total						
LQG	**1**	**9**	**44**	**23**	**53**	**20**
SQG		**4**	**10**	**8**	**15**	**6**

Sensitivity and Adaptive Capacity

The sensitivity and adaptive capacity of hazardous materials sites and the emergency response system in the ART project area were assessed for three potential climate impacts that could occur due to sea level rise and storm events. The three climate impacts considered were:

- More frequent or longer duration flooding during storm events
- Permanent or frequent inundation by the daily high tide
- Elevated groundwater levels and saltwater intrusion

Sensitivity is the degree to which an asset or entire system (e.g., an LQG site, CUPA, fire department, or SEMS) would be physically or functionally impaired if exposed to a climate impact. Adaptive capacity is the ability for an asset or system to accommodate or adjust to a climate impact and maintain or quickly resume its primary function. The sensitivity of hazardous materials sites depends both on the physical characteristics of each site, as well as on each individual facility's compliance with the Unified Program and other regulations, and on the region's emergency management capacity. Likewise, the adaptive capacity of a site depends on the ability to prevent the release of hazardous materials, and on the ability of responders to efficiently and thoroughly address any potential or actual release.

In the event of flooding during a storm event, hazardous materials could be released if their containers are spilled or broken; if floodwaters enter tanks and force out toxic liquids; or if uncontained wastes – in pits or piles – come into contact with floodwaters. Sites where materials are properly stored in watertight containers, especially if elevated above flood levels or easily moved, will be less sensitive than sites with improperly contained materials that are stored at ground level and are difficult to move. Hazardous materials sites could also be sensitive to rising groundwater if any materials are stored below ground.

The ability of any given facility to implement flood protection or flood proofing will contribute to adaptive capacity. Flood protection refers to structures that prevent floodwaters from entering a facility, such as dikes, berms, and floodwalls. Retrofitting facilities with flood protection can be quite costly, so flood proofing may be more realistic. Flood proofing includes features such as grading, fencing, upgrading containers' structural integrity, and elevating containers above flood levels. To the extent that a facility has already invested in such measures, it will have greater adaptive capacity. Sites with safe, elevated places to store materials also have adaptive capacity if materials can be moved in the event of a flood. Temporary measures, such as sand bags or pumps, and emergency plans for the removal of hazardous materials, also contribute to adaptive capacity.

The Unified Program requires hazardous material generators to have inventories of hazardous materials and contingency plans. If these documents are missing, incomplete, or out of date, it could hamper emergency response and cause a site to be more sensitive to sea level rise impacts than it otherwise would be. Adaptive capacity of individual sites and the emergency response system is increased by maintaining thorough, up-to-date documents under the Unified Program, and ensuring that CUPA leads are properly trained. In addition, local knowledge contributes to adaptive capacity if first responders such as fire engine companies are carrying out their duty to inspect and maintain records about hazardous materials' locations.

The layers of regulations and responders discussed above could contribute to both sensitivity and adaptive capacity. While the involvement of multiple agencies increases the resources available to respond to a flood and the potential release of hazardous materials, it could also open the door to confusion and inefficiency if plans are not well laid-out or executed. The potential for widespread flooding could also strain the capacity of emergency responders. While the Mutual Aid Agreement provides a process for agencies from the larger region and even the State to contribute in the event of an emergency, and agencies are accustomed to coordinating and sharing resources, a large storm on a long stretch of the California coast, coupled with a new high tide, could create so many emergencies – including, but not limited, to hazardous material releases – that an adequate response may not be possible.

Consequences

The potential consequences of the climate impacts on hazardous material sites and emergency response are considered for the ART project area. Consequences are addressed as the magnitude of the economic, social, environmental, and governance effects if an impact occurs. Factors that affect the consequences include the types of materials released, the extent of response required, the size and demographics of the population affected, and the types of natural resources affected.

Economy
The economic consequences of flooding for hazardous materials sites depends on whether or not materials are released into the environment; what types of materials are released; and the degree of emergency response necessary. If a release of non-waste materials occurs, the company will have lost either inputs or products, with consequences for material costs as well as lost profits. Whether or not released materials are waste, a thorough cleanup, with associated costs, will be required. In addition, responding to the actual or potential release of hazardous materials could strain the resources of local agencies such as fire and health departments. If the assistance of other agencies through the Mutual Aid Agreement or activation of EF-10 is necessary, further resources will be expended.

Society
One of the main consequences of a hazardous material release is the potential health effect on the exposed population. Although most floods that cause hazardous material releases do not cause serious outbreaks of chemical poisonings, they can cause sickness in workers and others who come in contact with contaminated floodwaters (OSHA fact sheet). Different chemicals cause different health effects. The signs and symptoms most frequently associated with chemical poisoning are headaches, skin rashes, dizziness, nausea, excitability, weakness, and fatigue. In addition, flooded areas may contain electrical or fire hazards due to downed power lines. Many chemicals and petroleum products are flammable or explosive. If such a material comes into contact with a downed wire, for example, fires and explosions could result. In addition to the effects of any one material, many facilities handle multiple types of wastes, some of which are "incompatible" – that is, if they mix, their hazardous properties such as toxicity and explosiveness increase. Such chemicals, if released during a flood, could come into contact with each other, causing further health and safety risks.

Environment
Flooding that causes a hazardous material release could also harm the environment. Depending on the substances released, they could sicken or kill wildlife and damage habitat. Many hazardous wastes are petroleum-based, so the environmental problems associated with oil spills could occur in the event of a hazardous materials release caused by flooding. Some hazardous materials are highly persistent, lasting for months and even years within an ecosystem. Some materials are also very mobile, meaning they can spread for long distances from their release point. Depending on the materials present, a release due to a climate impact could have a long-lasting, far-reaching effect on the environment.

Governance
In addition to the CUPAs and local responders, more than 25 State agencies are on call to become involved in the event of a hazardous materials release, and local agencies throughout

the county and region could also participate if resources in the immediate area are insufficient. An event over a large region could deplete resources and force agencies to prioritize sites, locations, and types of materials in their response. Despite the many plans at the site, local, State, and even federal level, there is room for confusion and overlap in coordinating and executing a response. In addition, as noted previously, it is difficult to quickly and accurately determine the locations of hazardous materials in the ART project area. There are many different databases addressing different materials, reporting systems, and regulations, some of which are out of date. Determining what might be exposed in the event of a climate impact, therefore, relies on CUPAs and local emergency departments keeping accurate, up-to-date files and making those available to emergency responders.

Key Findings

There are 152 sites that generate hazardous waste in the ART project area, concentrated largely in Oakland, Hayward, and Emeryville. Very few are exposed to the daily high tide or storm event flooding with 16 inches of sea level rise, but over one third are exposed to wind waves. With 55 inches of sea level rise, over 30 sites are exposed to the daily high tide, and nearly 100 sites are exposed to storm event flooding with wind waves.

It is difficult to assess the vulnerability of hazardous waste sites without knowing what types of wastes are exposed, and how they are stored and managed. One challenge is the lack of publicly available information, making it difficult to assess where hazardous materials are located and which sites will warrant a response in the event of a flood hazard or similar emergency. Publicly available, geo-referenced data does not include all hazardous materials sites (only sites that produce a certain quantity of hazardous wastes) or routes used to transport hazardous materials, which could also be exposed to sea level rise and pose a threat to human and environmental health.

Hazardous wastes are regulated by federal and state laws, many of which are implemented locally by Certified Unified Program Agencies (CUPAs). CUPAs keep information about where hazardous materials are stored within their jurisdiction, including types and amounts of materials at each location. While not available in a geo-referenced database, this information is available to emergency responders (and in fact in many cases the CUPA is housed within a fire department). While these regulations contribute to adaptive capacity, emergency responders in some cases may rely on local knowledge of hazardous materials sites, rather than standardized documentation, which could add to sensitivity.

As a category, hazardous materials have moderate vulnerability. Most are not exposed to 16 inches of sea level rise, and a suite of regulations exists to track the types, amounts, and locations of materials. However, this data may not be easily accessible by emergency responders, and the region may be unprepared for a multi-hazard, multi-site emergency involving hazardous materials.

References

California Code of Regulations (CCR). Title 22, Chapter 11, Article 3. http://www.dtsc.ca.gov/LawsRegsPolicies/Title22/OEARA_REG_Title22_Ch11.cfm.

Department of Toxic Substances Control (DTSC). 2010. Emergency Response Program Website. http://www.dtsc.ca.gov/SiteCleanup/ERP/index.cfm.

Occupational Safety and Health Administration (OSHA). Fact Sheets on Natural Disaster Recovery: Flood Cleanup. http://www.osha.gov/OshDoc/floodCleanup.html.

US EPA. *Hazardous Waste Website.* http://www.epa.gov/waste/hazard/index.htm.

Chapter 16. Energy, Pipelines, and Telecommunications Infrastructure

Energy, pipelines, and telecommunications infrastructure provide vital services within the ART project area and connect it with other parts of the region, state, nation, and world. Most, if not all, of the electricity consumed in the ART project area is produced outside of the subregion. However, there are two small power plants in the ART project area as well as infrastructure that transports electricity produced elsewhere to end users within and beyond the area. Pipelines carry petroleum and fuel from refineries outside of the ART project area to major end consumers within the area – such as Oakland Airport and truck terminals – and through the area to consumers elsewhere. Telecommunications infrastructure provides telephone and Internet services to residents and businesses in the subregion, connecting them to each other and with the rest of the world.

The components of the ART project area's electricity infrastructure addressed in this report are power plants, substations, and transmission lines. There are two power plants in the ART project area: an oil-powered plant in Oakland owned by Dynegy, and a natural gas and diesel plant in Alameda owned by the Northern California Power Agency (NCPA) (Table 1). The Dynegy plant is a peaking plant, meaning it only operates during times of high demand, and it provides power to the California Independent System Operator (CAISO).[1] The NCPA plant is a peaking and reserve plant. This means that these plants are not in use all the time, but only when other sources of electricity cannot meet demand. Data on where power produced by the Alameda NCPA power plant is consumed was not available.

Electricity is carried from where it is generated via high-voltage transmission lines, which can be overhead or underground. Major overhead electrical transmission lines run parallel to the shoreline. Substations link the energy transmission system to the distribution system,

Figure 1. Energy assets evaluated include substations, which connect transmission and distribution systems and are a critical component of the electricity system.

[1] The CAISO coordinates, controls and monitors the operation of the long-distance, high-voltage electrical power system for most of the State of California.

transforming power from the high voltage at which it is generated to a lower voltage for distribution to individual homes and businesses via overhead and underground utility lines. Substations also connect lines within both the transmission and distribution systems and are a critical component of the electricity system. Substations hold expensive and potentially dangerous equipment such as transformers, which change the voltage of electrical current; capacitors, which store energy in an electric field; and voltage regulators, which maintain a constant voltage. They can be aboveground in fenced enclosures, underground, or located in special-purpose buildings. There are 15 substations situated near the shoreline in the subregion (Table 1).

Table 1. Substations and power plants in ART project area

Name	Type of Asset	Operator	Location	Service Area*
Oakland P	Substation	PG&E	Oakland, near Bay Bridge onramp	Oakland
Maritime	Substation	Port of Oakland	Port of Oakland	
Schnitzer Steel	Substation	PG&E/Schnitzer Steel	Oakland, near Inner Harbor	Schnitzer Steel
Oakland C	Substation	PG&E	Oakland, near Jack London Square	Oakland
Oakland I	Substation	PG&E	Oakland, near Jack London Square	Oakland
Naval Supply Center	Substation	PG&E	Alameda	
NCPA	Substation	NCPA	Alameda	
Cartwright	Substation	AMP	Alameda	Alameda
Jenny	Substation	PG&E	Alameda	Alameda
Owens Brockway	Substation	Owens Illinois	Oakland, South	Owens-Brockway Glass Containers
Oakland J	Substation	PG&E	Oakland, South	Oakland
EDES	Substation	PG&E	Oakland, near Airport	Oakland, San Leandro
DOMTAR	Substation	Domtar Gypsum	San Leandro	Domtar Gypsum
Grant	Substation	PG&E	Hayward	San Leandro, San Lorenzo, Hayward, Cherryland, Ashland
Eastshore	Substation	PG&E	Hayward	Hayward
Oakland	Power Plant - Peaking	Dynegy	Oakland	CAISO
Alameda	Power Plant - Peaking & Reserve	NCPA	Alameda	

* Service area information was not available for all assets.

Natural gas is transported via underground pipelines. For example, there is a major natural gas pipeline owned by PG&E that parallels I-880. Liquid petroleum jet fuel, gasoline, and diesel fuels are also transported via pipelines that cross the ART project area. A pipeline owned and operated by Kinder Morgan enters the ART project area from the north and runs parallel to the shoreline to the Oakland Airport. The pipeline is buried in a raised dike along the edge of the airport, with five to six feet between the water level and the top of the dike, before crossing the Bay to the San Francisco Airport via Brisbane. In general, these pipelines are buried at a depth of 3 to 4 feet in high-carbon steel pipelines, and many are located in railroad and Caltrans right-of-ways. Some pipelines cross natural areas such as marshes and flood control and stream channels.

Telecommunication cables are usually buried underground at a depth of 2 to 5 feet or carried by overhead telephone lines. There are access points along the underground cables that allow for periodic maintenance and replacement. Many of the telecommunication lines in the ART project area are located in railroad and Caltrans right-of-ways.

The energy, pipelines, and telecommunications industries and infrastructure addressed in this report are regulated by a number of State and Federal agencies. The Department of Transportation's (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA), through the Office of Pipeline Safety (OPS), is the federal regulatory agency responsible for the oversight of pipeline safety. At the State level, the California Public Utilities Commission (CPUC) regulates electric and gas utilities, as well as some aspects of the telecommunications sector, and the State Fire Marshal acts as an agent of PHMSA with respect to pipeline safety. PHMSA regulations include safety-related requirements such as pipeline coating and burial depth, as well as periodic inspection of transmission pipelines, including surveying pipeline right-of-ways for excavation activities or population encroachment and detection of leaks and threats of corrosion. Utilities are also required to identify "High Consequence Areas" (HCA), such as areas with dense populations, and perform more rigorous inspections in these areas.

Exposure

Exposure is the extent to which an asset, such as a substation, power plant, or other infrastructure, experiences a specific climate change impact such as storm event flooding, tidal inundation, or elevated groundwater. This report analyzes the exposure of energy infrastructure in the ART project area to two sea level rise projections and three Bay water levels. The two sea level rise projections, 16 inches (40 cm) and 55 inches (140 cm), correlate approximately to mid- and end-of-century. These projections were coupled with three Bay water levels: the highest average daily high tide represented by mean higher high water (MHHW), hereafter "high tide" or "daily high tide;" the 100-year extreme water level, also known as the 100-year stillwater elevation (100-year SWEL), hereafter "100-year storm" or "storm event;" and the 100-year extreme water level coupled with wind-driven waves, hereafter "storm event with wind waves" or "wind waves." These water levels were selected because they represent a reasonable range of potential Bay conditions that will affect flooding and inundation along the shoreline. For more information about sea level rise projections and Bay water levels evaluated see Chapters 1 and 2.

Figure 2. Exposure of power plants and substations to daily high tide and storm events with 16 and 55 inches of sea level rise

Figure 2 and Table 2 summarize the exposure of power plants and substations. Exposure analysis was not performed for transmission lines, pipelines, or telecommunications infrastructure due to data limitations. Exposure was determined within a circular 164-foot (50-meter) diameter footprint centered on the point location of each plant or station (see Appendix C). This approach was verified as being representative of the approximate footprint of most assets evaluated in this manner. The average depth of inundation was calculated for the daily high tide and storm event scenarios. Whether the asset was exposed to wind waves only, or was within a disconnected low-lying area[2], was evaluated in a binary, i.e., yes versus no, analysis.

Table 2. Exposure of substations and power plants in the ART project area to 16 and 55 inches of sea level rise.

	16" SLR			**55" SLR**		
	Daily High Tide	**Storm Event**		**Daily High Tide**	**Storm Event**	
Asset	Average depth (ft)	Average depth (ft)	Exposed to wind waves only	Average depth (ft)	Average depth (ft)	Exposed to wind waves only
Oakland P Substation			Yes		2	
Maritime Substation			Yes		1	
Schnitzer Steel Substation			Yes		2	
Oakland C Substation			Yes		1	
Oakland I Substation			Yes		1	
Naval Supply Center Substation			Yes		2	
NCPA Substation			Yes		2	
Cartwright Substation			Yes		2	
Jenny Substation						Yes
Owens Brockway Substation						
Oakland J Substation		1	Yes	2	4	
EDES Substation			Yes	1	4	
DOMTAR Substation						
Grant Substation			Yes		3	
Eastshore Substation			Yes			Yes
Oakland Power Plant			Yes		1	
Alameda Power Plant			Yes		2	

[2] Disconnected low-lying areas are at the same elevation or are lower than an adjacent inundated area. Assets in these areas are not considered exposed because a topographic feature such as a railroad or road embankment should prevent inundation. However, they could be exposed if the protective feature fails. See Chapter 2 for a more detailed explanation.

With 16 inches of sea level rise, none of the substations or power plants evaluated are directly exposed to the new daily high tide. However, one substation, Oakland J, is in a disconnected low-lying area, and while not directly exposed, is potentially at risk of flooding depending on the type or condition of the topographic feature that prevents inundation or flooding. In addition, access to facilities located in low-lying areas could be limited if and when adjacent areas are inundated.

During a storm event with 16 inches of sea level rise, the Oakland J substation is exposed to 1 foot of flooding. The EDES and Grant substations are in disconnected low-lying areas adjacent to areas that will flood during a storm event, and are therefore are potentially at risk. All of the substations except for Jenny, Owens Brockway, and DOMTAR are exposed to wind waves during a storm event, as are both of the power plants.

With 55 inches of sea level rise, Oakland J and EDES substations are exposed to 2 feet and 1 foot of flooding, respectively, from the new daily high tide, and the Oakland power plant is in a disconnected low-lying area, and is therefore potentially at risk. Both of the power plants and all of the substations except for Jenny, Owens Brockway, DOMTAR, and Eastshore are exposed to 1 to 4 feet of flooding during a storm event, and all of the assets are exposed to wind waves except for Owens Brockway and DOMTAR substations.

Sensitivity and Adaptive Capacity

The sensitivity and adaptive capacity of energy, pipelines, and telecommunications infrastructure in the ART project area to three potential climate impacts that could occur due to sea level rise was assessed. The three climate impacts considered are:

- More frequent or longer duration flooding during storm events
- Permanent or frequent inundation by the daily high tide
- Elevated groundwater levels and saltwater intrusion

Sensitivity is the degree to which an asset or entire system (e.g., electricity generation, transmission, and distribution; fuel, oil, and natural gas conveyance; and telecommunications) would be physically or functionally impaired if exposed to a climate impact. Adaptive capacity is the ability for an asset or system to accommodate or adjust to a climate impact and maintain or quickly resume its primary function. The electricity, pipelines, and telecommunications infrastructure assessment considers various types of assets, with a correspondingly wide range of sensitivities. The sensitivity and adaptive capacity of individual assets, as well as each type of asset, as a system, is addressed below.

Energy Assets – Power plants, substations, and transmission and distribution lines

Power plants and substations are sensitive to flooding from storm events. They would also be sensitive to the daily high tide, but none of the assets analyzed here are exposed to this impact, although some are in disconnected low-lying areas that could be exposed. Further, it is unlikely that power plants or substations would be able to maintain function if inundated frequently or permanently, and it is assumed that they would be relocated if exposed to this impact. In the event of storm-related flooding, the equipment at power plants and substations could be damaged by water – particularly saltwater, which causes corrosion – as well as by any mud or debris that floodwaters could be carrying. If power plants were to be damaged by flooding, equipment may have to be replaced, resulting in a lengthy recovery period.

Other aboveground electricity infrastructure consists of overhead lines. These are not sensitive to flooding, unless waves or currents are so strong that they cause poles to topple. Electricity assets are not sensitive to rising groundwater, unless they have underground components –

such as a belowground floor of a substation with sensitive equipment that could be exposed to groundwater seeping into the building. Also, higher groundwater adds to liquefaction potential, which could make poles carrying transmission and distribution lines less stable in a seismic event.

Power plants and substations have a moderate degree of adaptive capacity. Power plants and substations can be shut down to prevent major damage from floodwaters such as corrosion to transformers, capacitors, switches and other equipment. The proper shutdown of power plants takes time, however, which adds to their sensitivity. With enough advance warning, some equipment can be moved – either to another location out of the flooded area, or raised to levels above the floodwaters. On-site protection measures such as sandbagging or pumping could also keep water away from sensitive equipment. The ability of substations to transfer electricity loads to other substations outside of the floodplain contributes to adaptive capacity of the system as a whole. Data was not available on whether there is any redundancy in distribution lines within the ART project area, which would allow operators to serve customers from different substations in the event that one or more substations are forced to shut down due to flooding. Emergency plans, such as having a shutdown plan and options for the removal of equipment in advance of a flood, are another important component of adaptive capacity. Having access to temporary, mobile substations to provide service while cleaning up damaged substations would also contribute to adaptive capacity.

Fuel, petroleum, and natural gas pipelines

The pipelines in the ART project area are buried several feet beneath the ground. In the event of flooding, pipelines that are not weighted or anchored may float and become exposed, particularly during prolonged flooding and in marshy or sandy soils. Erosion during storm events could also expose and damage pipelines. For example, heavy debris could dent or puncture the pipes, or in the event of a fully exposed pipe, swiftly moving water could move, bend, or break it, causing a leak. Aside from direct damage to cables and pipes, access to underground infrastructure could be compromised in the event of flooding, which could hinder any necessary maintenance.

Underground infrastructure such as pipelines could be sensitive to rising groundwater and saltwater intrusion, and some of this infrastructure is already exposed to such impacts. For example, some pipelines along the shoreline come into contact with groundwater every day as it rises and falls with the tide. However, government regulations require pipelines to be coated and cathodically protected[3] against corrosion. Following these guidelines lowers the sensitivity of such infrastructure to rising groundwater and saltwater intrusion. Another source of sensitivity to rising groundwater is the risk of liquefaction in a seismic event. The ART project area is in an area of high seismic vulnerability and liquefaction potential – the northern portion of the area, particularly the Emeryville, Oakland, and Alameda waterfront and Oakland International Airport fill areas, has a very high liquefaction susceptibility rating, while the southern portion including San Leandro, Hayward, and Union City, have a moderate liquefaction susceptibility rating (ART, 2011). Liquefaction and lateral spreading have caused damage to buried pipelines during past earthquakes in the region and in other parts of the world (Wang and Zhang, 1992; Tajika et al., 2008). With rising groundwater, the likelihood and extent of liquefaction will increase, magnifying the potential for damage to buried assets in a seismic event.

Adaptive capacity for pipelines derives in part from adhering to regulations such as those described above, as well as regular maintenance and procedures to monitor the condition of the

[3] Cathodic protection is a technique to control the corrosion of a metal surface by making the structure work as the cathode of an electrochemical cell.

pipes. Fuel pipelines are generally well protected – buried several feet below the ground surface (or streambed in the case of water crossings) or in a railroad embankment – and are hydro-tested or internally inspected at least every five years. If any damaged areas are found, the pipeline is dug up and repaired. Likewise, if storm event flooding were to damage a pipeline, valves could be closed on either side of the damaged area to minimize the quantity of material that could escape. This would disrupt service, and if reserves are low, operators may have to transport product by truck to meet demand. If pipelines were seriously threatened by sea level rise, they could be re-located, although this would be very capital intensive.

As with power plants and substations, a well-coordinated emergency response plan also contributes to adaptive capacity. If fuel or gas pipelines are compromised, responders need to know where infrastructure is located; have a plan to isolate the problem, for example by closing valves and removing product; be ready to counteract any consequences such as leaking fuel or escaping gas and associated fire hazards; and have a plan to restore service. Further, the sensitivity and adaptive capacity of the entire system – of electricity transmission and distribution, and of pipelines – depends on the ability of operators and emergency responders to handle any impacts that might occur. A flooded substation, for example, would be the responsibility of the owner/operator; therefore, areas in which many assets owned by the same company are exposed to the same impact may be particularly sensitive, since that company could be stretched thin in the event of flooding. If a pipeline carrying fuel is compromised, it will involve the owner, as well as emergency responders and a number of agencies responsible for environmental protection, public health, and other elements of the community that would be affected by an accidental release.

Adaptive capacity is also built through awareness and planning ahead. PG&E, for example, formed a cross-departmental Climate Change Operational Impact Team in 2008, which conducts bi-annual reviews of scientific literature on sea level rise and other climate impacts. These reviews are intended to identify climate risks to facilities and inform the development of adaptation strategies (PG&E, 2011). While sea level rise is currently considered a "low-medium" risk, the company states that they are aware of potential risks and will address them over time.[4]

<u>Telecommunications infrastructure</u>

Telecommunications cables and wires run both overhead and underground. Overhead telecommunications lines, like electricity transmission and distribution lines, have low sensitivity to flooding and rising groundwater. Underground cables, however, could be sensitive to severe flooding if erosion occurs – in Queensland, Australia, for example, cables buried 1.5 meters deep were severed during an extreme storm in 2011 (Braue, 2011). Cables that are buried above the current water table could be sensitive to rising groundwater and saltwater intrusion if they were not designed to withstand such conditions, and liquefaction in an earthquake could cause them to shift and break. Flooding could also impair access to underground infrastructure, which could prevent or delay repairs. Power is required for many cellular telecommunication facilities to operate, and on-site backup power is generally not required, linking cellular functionality to the vulnerability of the electrical grid.

As is the case with electricity substations, adaptive capacity in telecommunications comes in part from the ability to shift loads to unimpaired infrastructure. Adaptive capacity of the system is enhanced by replication – that is, the multiple channels available for communication – through mobile phones, landlines, and through the Internet, for those with access. Given the rapidly changing nature of the telecommunications sector, it is difficult to predict what types of

---

[4] PG&E has not had access to elevation data that is sufficiently accurate for the company to assess the risk to its infrastructure from sea level rise flooding; more accurate data should be made available to the company to facilitate the evaluation of risk to exposure.

technology will be in use over the time scale considered in this report, but the basic principles of flexibility and overlap should still contribute to adaptive capacity.

Consequences

The potential consequences of the climate impacts on the energy, pipelines, and telecommunications infrastructure are considered for the ART project area. Consequences are the magnitude of the economic, social, environmental, and governance effects if an impact occurs. Factors that inform the magnitude of the potential consequences include the severity of the impact on operations and maintenance or capital improvement costs, the size and demographics of the population affected, and the types of natural resources affected.

Economy

Energy, pipelines, and telecommunications infrastructure provide vital services within the ART project area, as well as linking it to regions outside the area. The disruption of this infrastructure could therefore have serious economic consequences. If substations or power plants are threatened with flooding, they will be shut down, and if equipment is damaged they could be out of service for some time. Repair or replacement of damaged equipment could be quite expensive. As discussed above, managers may be able to shift electricity loads to other substations. If not, however, the areas served by flooded substations would lose power until any damaged or moved equipment is repaired or replaced. Loss of power can range from an inconvenience, if only for a short duration, to a serious problem if power is out for a long time, as it could result in a loss of productivity due to workplaces and schools being closed.

If fuel, petroleum, or natural gas pipelines are disrupted and alternate forms of transportation are unavailable or too costly, end users – such as the Oakland Airport – could be forced to suspend operations, which could have serious economic consequences. Managers try to ensure that there is a reserve available, and fuel can be trucked if the pipelines are out of service, but trucking fuel is more expensive than transporting it via pipeline. Further economic consequences in the form of operations and maintenance and capital improvement costs could occur if any pipelines are damaged and have to be repaired, or, as a last resort, re-located. In the event that a climate impact actually results in a release of fuel or natural gas, cleanup costs could also be quite high.

If telecommunications infrastructure such as telephone lines and Internet cables were to be impaired by flooding, it could seriously disrupt business operations, with corresponding economic consequences. Repairing any damaged infrastructure would also incur costs.

Society

Since the power plants in the ART project area are peaking and reserve plants, there would only be consequences in the form of a power shortage if a sea level rise impact occurred during a time of peak demand or if base plants were disabled at the same time. Further, because the Oakland power plant provides power to the CAISO rather than directly to the region, the ART project area may not be affected if it is shut down. If power is disrupted, either due to power plants or substations being affected by a climate impact, the consequences for society could be fairly serious – in addition to lost productivity from the closure of schools and workplaces, many other important services rely on power being available. For example, telecommunications and pumps, which are vital during an emergency, could be forced out of service unless backup power is available. Power outages also pose health risks for residents who rely on home medical equipment such as ventilators and oxygen concentrators, which require electricity to function. A prolonged power outage could also make it difficult for residents to heat and light their homes or cook if they rely solely on electricity for these services.

The societal consequences of a climate change impact on pipelines are likely to be minimal to moderate, depending on the severity of disruption to the transportation of fuel and natural gas. However, if a fuel or natural gas pipeline were to leak or explode, due for example to liquefaction in a seismic event, there could be serious consequences for the life and health of those in proximity to such an incident.

If telecommunications infrastructure is directly affected by a climate impact, it could hamper emergency response as well as everyday communication needs. Cellular networks could enable basic communication to carry on, although if electricity services are impaired, people will be unable to charge their mobile phones and cellular facilities that rely on power to operate may go out of service. Residents who rely on landline services and do not have access to cellular or Internet services would be particularly affected by the effects of a climate impact on electricity and / or telecommunications, as they would have fewer options to communicate with emergency responders and family members. This could have equity implications, as such individuals are often among the elderly or low-income populations.

Environment

There could be environmental consequences of a climate impact on power plants and substations if fuels such as oil or diesel, or other materials used in these facilities were to be moved offsite by floodwaters. As noted above, if liquefaction in a seismic event caused a pipeline to leak or explode, the environmental consequences could be significant, especially where pipelines run through sensitive areas such as marshes and wetlands.

Governance

Most of the assets covered in this section are privately owned but regulated by a number of state and federal agencies. Governance consequences depend on the type of impact – for example, releases of materials from power plants or pipelines could involve PHMSA and the CPUC, not to mention emergency responders and environmental agencies. A coordinated response can be challenging to implement, especially if multiple facilities are affected at once, which could overwhelm asset owners, emergency responders, and regulatory agencies.

Key Findings

The energy, pipelines, and telecommunications infrastructure assessed for the ART project area includes power plants, substations, transmission lines, natural gas and liquid petroleum pipelines, telephone poles, and underground cables. Geo-referenced data was only available for power plants and substations, and these were the only assets for which an exposure analysis was conducted. Of the 15 substations and two power plants in the ART project area, none are exposed to the daily high tide with 16 or 55 inches of sea level rise, but almost all are exposed to wind waves with either amount of sea level rise. All but four of the assets evaluated are exposed to storm event flooding with 55 inches of sea level rise.

Aboveground energy infrastructure such as substations and power plants are very sensitive to water. These assets would need to be shut down to prevent damage if exposed, and even so, damage to sensitive equipment could still occur. Underground assets such as pipelines and cables are less sensitive than aboveground infrastructure, but the consequences if they are affected can be very high. For example, if a liquid fuel pipeline were to break during a seismic event due to increased liquefaction caused by elevated groundwater levels, surrounding natural resources and wildlife could be seriously affected.

The adaptive capacity varies depending on the type of asset considered. Telecommunication systems have fairly high redundancy, which contributes to this asset's fairly high adaptive capacity. For example, there are multiple options for communication such as Internet, landline, and mobile phones. Pipelines regulations mandating protection against corrosion and the placement of shutoff valves contribute to adaptive capacity for this system of assets, while flexibility in load shifting would increase the adaptive capacity of energy infrastructure.

There is a general lack of information for these systems of assets, which increases vulnerability. For example, the location of telecommunications infrastructure was not available, and such information may be lost as older technologies are abandoned and new ones are implemented. Information about plans for shutting down power plants and substations and moving sensitive equipment above flood levels was not available, nor was information available about redundancy among electricity substations.

Given the lack of exposure data and overall information about the type and location of the different assets, the overall vulnerability of this asset category cannot be determined at this point. It would be worthwhile to conduct further analysis, not only because there are fairly high potential consequences if these assets were to be compromised, but also because of the role they play in the event of an emergency. For example, telecommunications and electricity are critical during a flood in order to coordinate response, pump floodwater away from people and vital infrastructure, assist with rescue, and initiate recovery actions.

References

Adapting to Rising Tides (ART). 2011. Adapting to Rising Tides Transportation Vulnerability Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project. November 2011. Prepared by AECOM and Arcadis for the San Francisco Bay Conservation and Development Commission, Metropolitan Transportation Commission and the California Department of Transportation. Available at http://www.mtc.ca.gov/news/current_topics/10-11/sea_level_rise.htm.

Braue, D. 2011. Telecoms lessons learnt in the flood. In ZD Net, January 18, 2011. http://www.zdnet.com.au/telecoms-lessons-learnt-in-the-flood-339308645.htm.

Pacific Gas & Electric (PG&E). 2011. Carbon Disclosure Project Investor Response 2011. https://www.cdproject.net/en-US/Results/Pages/responses.aspx.

Tajika, H., H. Horikawa, and N. Suzuki. 2008. Analysis of Buried Pipeline due to Liquefaction-Induced Permanent Ground Deformation. International Gas Union Research Conference, Paris, 2008.

Wang, L.R.L., and H. Zhang. 1992. Buried pipeline system in a liquefaction environment. Earthquake Engineering, Tenth World Conference.

Adapting to Rising Tides Survey

1. Background Questions

Thank you for taking the time to complete the Adapting to Rising Tides (ART) Vulnerability and Risk Assessment Survey. The purpose of this survey is to get your best professional judgments of how sea level rise and storm event impacts will affect the services, facilities, and systems that you plan for, operate, and/or manage.

NOTE: The survey takes 30 - 45 minutes to complete. It cannot be saved in the middle, and it must be completed on a single computer. It consists of both multiple choice and essay questions, some of which address complex concepts. We recommend reviewing the entire survey and applicable supplemental information before starting to answer questions to minimize the amount of time it will take you. A printable (PDF) version of the survey, as well as supplemental information are at ART survey website: https://sites.google.com/site/artvandrsurvey/

The survey has four sections:

1. BACKGROUND information about your area of expertise and the service, facility, or system that you wish to address in the survey.

2. VULNERABILITY ASSESSMENT consisting of three parts - exposure, sensitivity, and adaptive capacity. There are no questions in the exposure subsection; it has information about exposure that will help guide your answers about impacts. Questions about sensitivity and adaptive capacity are a combination of multiple choice and essay/comments.

3. RISK ASSESSMENT consisting of questions about the consequence, or magnitude of effect, on social, economic, environmental, and governance systems.

4. EQUITY consisting of questions about equity issues in the ART subregion that relate to sea level rise and storm event impacts.

Your responses to the following survey are confidential. BCDC and ART project partners will not directly quote any of your information without your explicit consent.

1. What is your name?

***2. What agency or organization do you work for?**

***3. What department, section or unit do you work for within your agency or organization?**

4. What is your job title?

Adapting to Rising Tides Survey

*5. Which of the following is your primary focus in your job? (check only one)

- ○ Airport planning, operations, management
- ○ Community land use planning
- ○ Community services
- ○ Contaminated lands (landfill, superfund, cleanups)
- ○ Emergency response planning and management
- ○ Energy infrastructure
- ○ Ground transportation (roads, rail, transit)
- ○ Hazardous material sites (RCRA, CUPA, etc)
- ○ Natural area management/preservation
- ○ Parks and recreation areas (including Bay Trail)
- ○ Pipelines or gaslines
- ○ Public health
- ○ Seaport planning, operations or management
- ○ Stormwater management
- ○ Structural shorelines - flood control
- ○ Wastewater services
- ○ Other

Other (please specify)

*6. What geographic area within the ART project area will you be considering when responding to the questions in this survey?

(Note: Please respond for the geographic area where you have expertise.)

- ○ ART project area (entire)
- ○ Emeryville
- ○ Oakland
- ○ San Leandro
- ○ San Lorenzo
- ○ Hayward
- ○ Union City
- ○ Port of Oakland
- ○ Other

Other (please specify)

Adapting to Rising Tides Survey

***7. This survey asks you to evaluate the vulnerability and risks of an asset in the ART study area to the impacts of sea level rise and storm events.**

Assets are the services, facilities and systems that you plan for, operate and/or manage. Examples of assets include a park, a wastewater treatment facility, an airport runway, a neighborhood, a pipeline, a wetland, a Bay Trail segment, etc.

Describe the asset that you will address in this survey. Please provide information about the physical aspects of the asset, its functions, its components or parts, and if it is part of a larger system.

NOTE: If there are additional assets for which you can provide information, ART project staff want your input on each of these. To help us avoid confusion in interpreting your responses, please fill out a separate survey for each distinct asset. To do this go to the ART survey website (https://sites.google.com/site/artvandrsurvey/) and click on a new survey link for each asset for which you are responding.
Thank you!

Adapting to Rising Tides Survey

2. Vulnerability Assessment - Exposure

Exposure is the extent to which an asset experiences a specific climate impact, e.g., storm event flooding, tidal inundation or elevated groundwater levels.

To help determine if assets in the ART project area will be exposed to these impacts, refined sea level rise and storm event maps were developed by a coastal engineering consultant. These maps use current climate projections; however, there remains significant uncertainty as to the timing and extent of sea level rise and changes in storm event intensity or frequency. Additionally, the maps are based on model outputs and are therefore only an approximation of potential future conditions.

The goal of this survey is to understand how assets in the ART project area will be affected by future sea level rise and storm events. Please use the maps only as an indicator of potential future conditions; for example, whether the asset has the potential to be exposed to new, daily high tide inundation and/or to new storm event flooding. Please also use your knowledge of the geographic area, the asset, and any past experience with flooding or storms to answer the following questions.

Exposure maps for the ART project area can be viewed at:
https://sites.google.com/site/artvandrsurvey/

Note: Because there are no regional or site-specific studies of how groundwater will respond to sea level rise, the ART project is adopting a simplified assumption that groundwater will rise in correspondence with the bay, i.e., 16 inches or 55 inches.

Adapting to Rising Tides Survey

3. Vulnerability Assessment - Sensitivity

In this part of the survey, please assess the “sensitivity” of your asset to the impacts of sea level rise and storm events.

Sensitivity is the degree to which an asset is impaired by a climate impact. Assets with high sensitivity are likely to be greatly impaired (physically or functionally) by sea level rise and storm events, while assets with low sensitivity are likely to be minimally impaired.

Example: Consider two homes built at the same elevation in an area with a high risk of storm event flooding. The first home is built with its first floor just at the 100 year (1% chance) flood level. The second is built with its first floor elevated 2 feet above the 100 year (1% chance) flood level. When a historically high flood event hits the area, the first house is severely damaged and remains uninhabitable for a month, while the second home is not affected. Both homes have the same amount of exposure to the flood event; however the first home has higher sensitivity.

***1. What is the existing (current) physical and functional condition of the asset you listed? Are there stressors – such as lack of agency/organization capacity, budget constraints, or weather conditions – that currently impair its physical condition and/or functions? If so, please explain how.**

***2. Is the asset that you listed currently affected by flooding and/or extreme weather events? If so, please explain how.**

Adapting to Rising Tides Survey

***3. If exposed to the following impacts of sea level rise and storm events, would the asset that you listed be impaired physically or functionally?**

	Yes	No	Not Sure
Storm event flooding	○	○	○
Inundation at high tide	○	○	○
Elevated groundwater and salt water intrusion	○	○	○

If you answered "Yes" for any of the impacts above, how would the asset be impaired? (For example, are there parts or components of the asset that would be more or less sensitive?) If you answered "Not Sure" for any of the impacts please also explain your uncertainty.

Now, please evaluate the sensitivity of your asset to the impacts of sea level rise and storm events using the rating scale below to answer the next question.

Sensitivity	
S0	Asset will not be impaired by the impact
S1	Asset will be minimally impaired by the impact
S2	Asset will be somewhat impaired by the impact
S3	Asset will be largely impaired by the impact
S4	Asset will be completely impaired by the impact

***4. Based on your best professional judgment, what sensitivity level would you give the asset for each of the following impacts:**

	S0	S1	S2	S3	S4
Storm event flooding	○	○	○	○	○
Inundation at high tide	○	○	○	○	○
Elevated groundwater and salt water intrusion	○	○	○	○	○

Please provide details about your ratings. If you were uncertain about how to rate the sensitivity, please explain your uncertainty.

Adapting to Rising Tides Survey

5. Are there efforts (e.g. plans, programs, funding sources) underway that would improve the physical condition or function of the asset and reduce its sensitivity to climate impacts?

Adapting to Rising Tides Survey

4. Vulnerability Assessment - Adaptive Capacity

In this part of the vulnerability assessment, please evaluate the “adaptive capacity” of your asset to the impacts of sea level rise and storm events.

Adaptive capacity is the inherent ability of an asset to accommodate or adjust to a climate impact in order to maintain its primary functions. This includes the capacity of the asset to be quickly, easily, or in a low-cost manner returned to function.

Example 1: Consider two homes built in an area with equal flood risk. Both homes have a first floor at the elevation of the 100 year (1% chance) flood level. The first home is not designed to cope in the event of a flood and is built with materials that cannot tolerate moisture. The second home is designed to pump out water that gets above 1 inch and is built with moisture tolerant materials. Both houses flood when a historically high flood event hits the area. The first house has water levels that reach nearly 8 inches and due to the moisture begins to mold. It remains uninhabitable for months. The second home starts pumping the water out immediately, and because of its moisture tolerance, is re-inhabited two days later. Both homes have the same sensitivity, but the first home has a lower adaptive capacity.

Example 2: Consider two parks that are similarly affected by storm flooding (e.g. with debris, paths washed out, structures damaged, etc.). Both are forced to close. The first park has an active and dedicated "Friends of the Park" association that mobilizes donors and volunteers to take care of clean-up and repairs, enabling the first park to reopen within a month. The second park lacks this type of support organization and remains closed for much longer as a result. The parks had the same sensitivity to storm impacts, but the first park has a higher adaptive capacity.

***1. Does the asset have core qualities that would allow it to be quickly, easily, or in a low-cost manner restored to function if disrupted or disabled due to the following impacts?**

	Yes	No	Not Sure
Storm event flooding	◯	◯	◯
Inundation at high tide	◯	◯	◯
Elevated groundwater and salt water intrusion	◯	◯	◯

If you answered "Yes", please describe the core qualities. If you answered "No" for any of the impacts in this question, please describe what could be done to improve the capacity of the asset to deal with the impacts. If you answered "Not Sure", please also explain your uncertainty.

Adapting to Rising Tides Survey

2. If the asset is partially compromised or disrupted by the impacts, would it retain its primary function? If so, please describe to what degree. Additionally, describe which components of the system as a whole are critical to the overall function of the asset.

Now, please evaluate the adaptive capacity of your asset to the impacts of sea level rise and storm events. Please use the rating scale below to answer the next question.

Adaptive Capacity	
AC0	Asset will not be able to accommodate or adjust to impact
AC1	Asset will be minimally able to accommodate or adjust to impact
AC2	Asset will be somewhat able to accommodate or adjust to impact
AC3	Asset will be mostly able to accommodate or adjust to impact
AC4	Asset will be able to accommodate or adjust to impact

***3. Based on your best professional judgment, what adaptive capacity level would you give the asset for the impacts?**

	A0	A1	A2	A3	A4
Storm event flooding	○	○	○	○	○
Inundation at high tide	○	○	○	○	○
Elevated groundwater and salt water intrusion	○	○	○	○	○

Please provide details about your ratings. If you were uncertain about any of your ratings, please also explain your uncertainty.

Adapting to Rising Tides Survey

The examples provided below are intended to help you answer the next question.

Examples of Resources to Enhance Adaptive Capacity					
	Economic	**Environmental**	**Governance**	**Societal**	**Technology/ Infrastructure**
Low	• No legal authority to raise funds • No strong tax base to call upon • No private sector interest	• No marsh or dune system provides storm protection • All habitat is isolated and disconnected from other natural areas	• No interagency collaboration • No support from higher levels (county, state, etc) • No public participation	• Disenfranchised or uninvolved citizenry • Lack of community & aid organizations • Limited access to information for citizenry	• Use of outdated materials and structural codes • No system for integrating new knowledge into changes
High	• Mechanism for raising funds exists • Very strong tax base to call upon • Heavily involved private sector	• Highly functioning marsh or dune system provides storm protection • Habitat systems are connected allowing for species and sediment movement	• Good interagency collaborative processes • Work closely with higher levels (county, state, etc) • Heavily involved citizenry	• Citizens are heavily involved in their communities • Active and effective community & aid organizations • Citizens have access to information	• Most structures are new and have used the latest materials & structural codes • New knowledge is regularly integrated into purchasing agreements

***4. For each of the following five areas, what level of resources is available for enhancing the adaptive capacity of the asset?**

	Very low	Low	Medium	High	Very high
Economic	○	○	○	○	○
Environmental	○	○	○	○	○
Governance	○	○	○	○	○
Social	○	○	○	○	○
Technology / Infrastructure	○	○	○	○	○

Please provide additional information on each of the ratings you provided.

Adapting to Rising Tides Survey

5. Are there efforts currently underway to enhance the adaptive capacity of the asset?

Adapting to Rising Tides Survey

5. Risk Assessment - Consequences

In this part of the survey, please evaluate the “consequences” of sea level rise and storm event impacts. Consequence is the magnitude of the social, economic, legal, and environmental effects if an impact occurs.

In assessing consequences, it is useful to consider factors such as:
- The estimated scale of the impact (e.g., the size of the population, land area, resources, etc. that would be affected by the impact).
- The severity of the impact (e.g., total loss versus more frequent but minor damage that can be repaired).
- Cumulative costs or harm associated with a higher frequency of relatively minor events (e.g., flooding from smaller storms).

Please consider the consequence of an impact to the asset and its primary function, as well as to the greater community and/or system as a whole. The consequences of an impact on an asset can be significant for both the managing agency or organization and the greater community or system (for example, loss of an essential sewage pumping station). Both of these consequences are important to understand when identifying and prioritizing adaptation strategies.

*** 1. What is the expected magnitude of the effect on the Economy if the asset experiences the following impacts? Example questions to consider:**

- Is there a disruption to the goods movement network?
- Is there a disruption to job / employment centers?
- Are there costs associated with repair, replacement, and re-opening of the asset?

1 = very small magnitude of Economic impairment
5 = very large magnitude of Economic impairment

	1	2	3	4	5
Storm event flooding	○	○	○	○	○
Inundation at high tide	○	○	○	○	○
Elevated groundwater and salt water intrusion	○	○	○	○	○

Please provide details about your ratings. Specifically, describe the highest magnitude consequence ratings.

Adapting to Rising Tides Survey

***2. What is the expected magnitude of the effect on Society if the asset experiences the following impacts? Example questions to consider:**

- Is there a potential for public health and safety-related impacts?
- Is there a loss of recreational opportunities or shoreline access?
- Does the asset support an underserved community?
- Does the asset serve individuals or communities with limited mobility such as elderly, disabled, or transit-dependent populations?

1 = very small magnitude of Societal impairment
5 = very large magnitude of Societal impairment

	1	2	3	4	5
Storm event flooding	◯	◯	◯	◯	◯
Inundation at high tide	◯	◯	◯	◯	◯
Elevated groundwater and salt water intrusion	◯	◯	◯	◯	◯

Please provide details about your ratings. Specifically, describe the highest magnitude consequence ratings.

Adapting to Rising Tides Survey

***3. What is the expected magnitude of the effect on the Environment if the asset experiences the following impacts? Example questions to consider:**

- Will there be an impact or disruption to ecosystem services such as flood protection?
- Will populations of threatened or endangered species be impaired?
- Does the asset serve as an important ecological corridor or serve as an important link in a large habitat network?

1 = very small magnitude of Environmental impairment
5 = very large magnitude of Environmental impairment

	1	2	3	4	5
Storm event flooding	◯	◯	◯	◯	◯
Inundation at high tide	◯	◯	◯	◯	◯
Elevated groundwater and salt water intrusion	◯	◯	◯	◯	◯

Please provide details about your ratings. Specifically, describe the highest magnitude consequence ratings.

Adapting to Rising Tides Survey

***4. What is the expected magnitude of the effect on Governance if the asset experiences the following impacts? Example questions to consider:**

- Will the impact result in an unclear legal or regulatory situation (e.g. lack of clear responsibility or authority) or inadequate regulatory or legal framework?
- Will the impact stress current inter-agency coordination or overwhelm current capacity to respond in a coordinated manner?
- Will the impact result in the current planning processes, timeframes, or decision structures being inadequate or inappropriate?

1 = very small magnitude of Governance impairment
5 = very large magnitude of Governance impairment

	1	2	3	4	5
Storm event flooding	◯	◯	◯	◯	◯
Inundation at high tide	◯	◯	◯	◯	◯
Elevated groundwater and salt water intrusion	◯	◯	◯	◯	◯

Please provide details about your ratings. Specifically, describe the highest magnitude consequence ratings.

Adapting to Rising Tides Survey

6. Equity and ART

The effects of sea level rise and storm events may disproportionately affect some communities. Many traditionally disenfranchised communities already confront a variety of issues including food security and access to education and health care. Flooding and other impacts associated with climate change may create added equity challenges as well as opportunities for building resiliency. Equity can be defined as “fair access to livelihood, education and resources; full participation in the political and cultural life of the community; and self determination in meeting fundamental needs” (Ecotrust, 2011). Additionally, communities that may be uniquely affected by sea level rise should be considered, such as households with no car, and less mobile or institutionalized populations. To adequately reduce and manage climate risks for Bay Area communities overall, equity issues must be evaluated and then addressed by the strategies that we employ to adapt to changing climate conditions. A priority for this stage of the ART project is to develop a reproducible method for integrating equity into our understanding of the ways communities and vital assets will be affected by sea level rise.

The following portion of the survey is intended to collect baseline information about equity issues related to sea level rise and storm event impacts within the study area of the ART project, and for the larger San Francisco Bay Area. Results from this survey will be used to highlight major equity considerations in the ART project, including a white paper on equity and sea level rise that will be published in Spring/Summer 2012.

By answering the following questions, you are assisting the ART project team in developing this approach and contributing to a greater understanding of the issue of equity in the region. We are greatly interested in hearing your feedback and thoughts on this issue. If you would like to discuss the issues raised in this survey in greater deal with project staff, please email Heidi Nutters at heidin@bcdc.ca.gov.

Adapting to Rising Tides Survey

***1. Please mark the primary areas that you are most concerned about for equity and sea level rise. Select all that apply.**

- [ ] Public health (e.g., Health impacts of contamination from sewage conveyance and treatment systems; groundwater intrusion into contaminated sites remobilizes contaminants)
- [ ] Emergency preparedness and/or disaster response (e.g., Greater consequences from earthquakes due to elevated groundwater levels; poor quality or quantity of emergency response services in communities of concern)
- [ ] Disaster recovery (e.g., Increased cost of repair and maintenance after flood slows recovery in communities of concern; disadvantaged communities bear disproportionately high burden of effects; longer duration or disruption of access to goods particularly in low income communities)
- [ ] Economic effects (e.g., Increased cost of repair and maintenance after flood events slows recovery in communities of concern; lost wages and lower productivity in the region during recovery periods; higher insurance rates due to greater flood risks)
- [ ] Institutional/Governance (e.g., Greater demands on agencies to plan for and manage infrastructure/resources; building codes and land-use policies and practices inadequate to address sea level rise impacts)
- [ ] Flooding of critical infrastructure and/or neighborhoods in low-income communities (e.g., Overwhelmed flood protection channels and storm drains increase flooding in low-lying areas; inundation of existing private and public infrastructure and critical facilities; structures, including shoreline protection, that are not adequately protected, elevated or flood-proofed are destroyed or damaged)
- [ ] Public access, ecosystems and recreation (e.g., Loss of trails, beaches, vistas, other shoreline recreation areas and public access to shoreline over time; loss of tidal habitat which can reduce flood protection benefits of tidal marsh and mudflats to inland communities)
- [ ] Effects on community services (e.g., Longer duration or disruption of access to services particularly in low income communities)
- [ ] Transportation justice (e.g., Disruption to key transportation services to disadvantaged communities)
- [ ] Other, please explain.

Other (please specify)

Adapting to Rising Tides Survey

***2. For the issues you identified above, mark the populations that you think will be most affected and/or disproportionately burdened by sea level rise and flooding. If a population of concern is not listed here, please list it below. If you think one of these demographics should be described differently, please note that below.**

- [ ] Persons with limited mobility or with a disability
- [ ] Renters
- [ ] People of color
- [ ] Low-income people
- [ ] Seniors over 75
- [ ] Institutionalized populations (People in hospitals, nursing homes and prisons)
- [ ] Households with limited English proficiency
- [ ] Households with no vehicle
- [ ] Other

Other (please specify)

Adapting to Rising Tides Survey

3. In your opinion, what would a resilient, socially just response to the community impacts of sea level rise and storm events look like?

4. Sea level rise and storm events present new challenges for engaging disenfranchised communities in decision-making, but this region has a rich history of community efforts from which to build. Based on your experience and knowledge of engaging communities, what advice would you give for bringing communities of concern into conversations about sea level rise and storm event risks related to climate change?

Adapting to Rising Tides Survey

***5. As we begin to address sea level rise and storm events in planning, what do you foresee as the biggest challenges to addressing equity issues in these processes? What is needed to overcome these challenges?**

Adapting to Rising Tides Survey

7. Thank You

Thank you very much for taking the time to complete this survey. We greatly appreciate your participation.

You are officially finished!

1. Are you interested and willing to be quoted directly in the report for the ART vulnerability and risk assessment?

- ◯ Yes
- ◯ No

If you answered "Yes" please provide your contact information (name, email and phone number)

B4.4 Inundation Mapping

Six inundation scenarios were evaluated as part of this effort. 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. 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. 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 NOAA 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.

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.

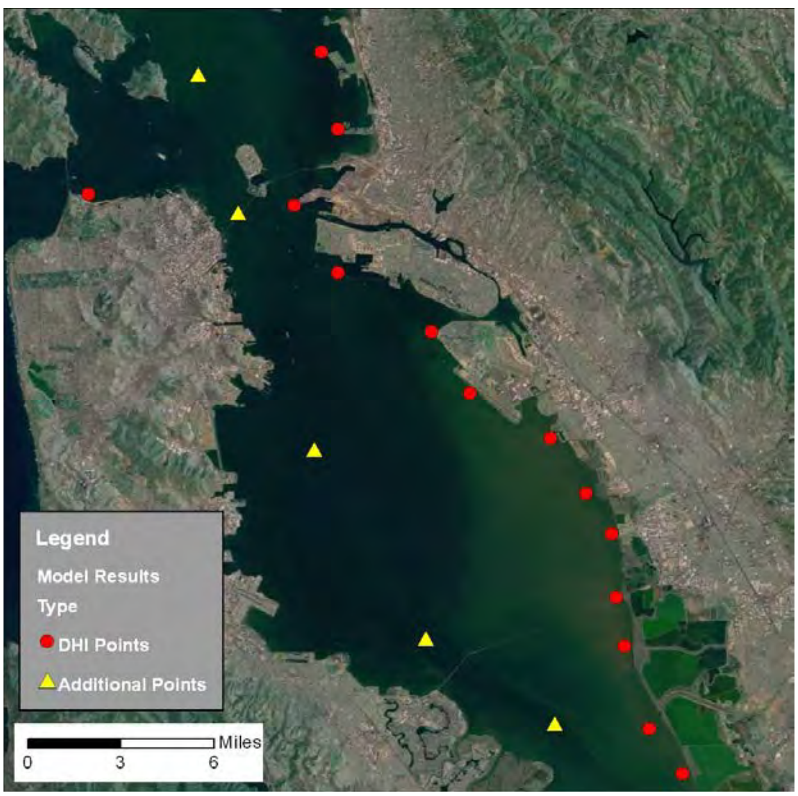


Figure B4.8. DHI and USGS Model Extraction Points within the Project Area

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)

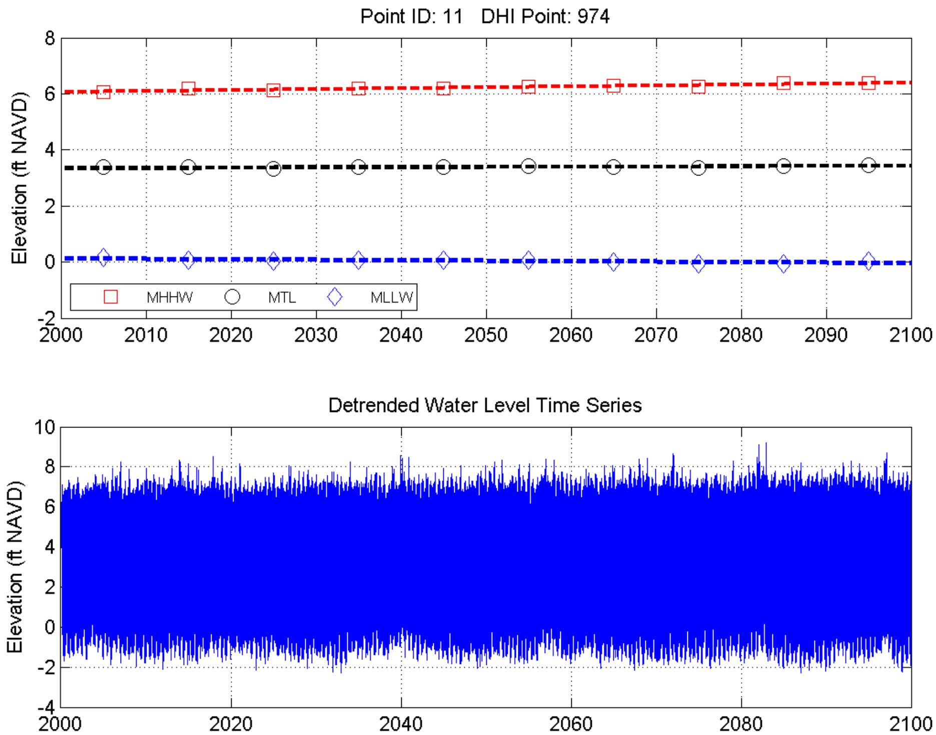


Figure B4.9. Stationarity Analysis and Trends for Sample Model Extraction Point along Alameda County Shoreline

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.

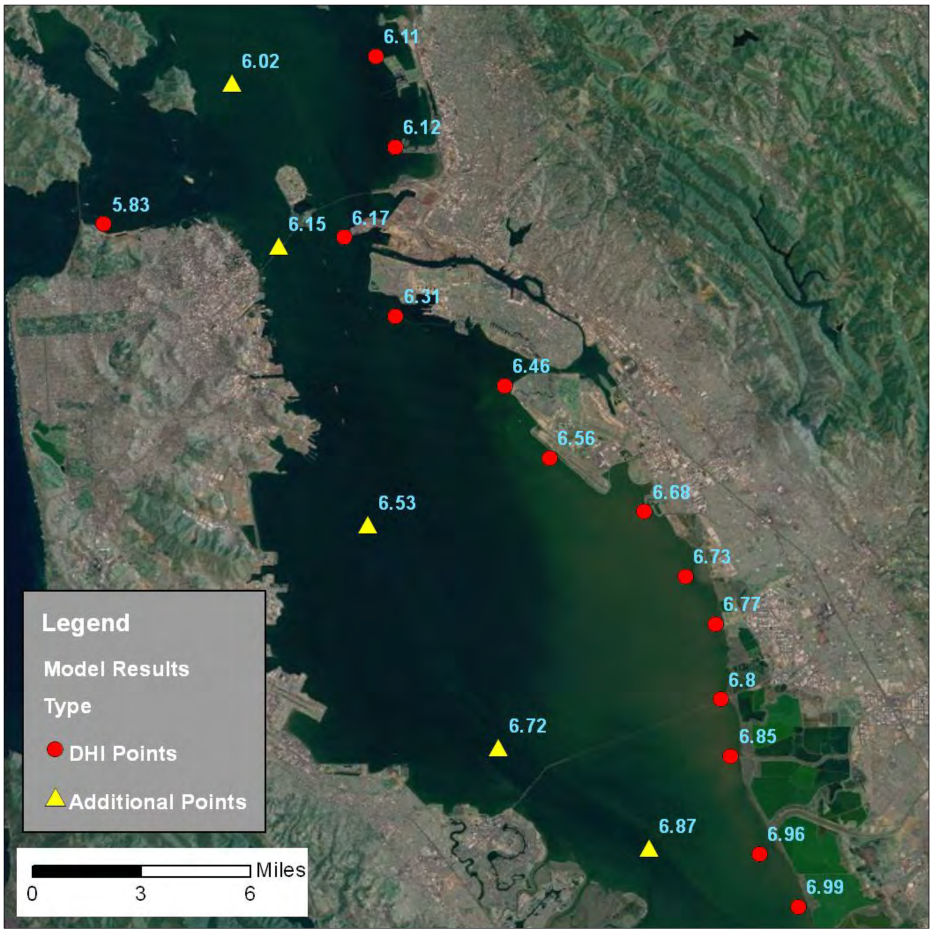


Figure B4.10. Average Daily Tide Elevations (MHHW Tidal Datum) for Existing Conditions Determined from USGS TRIM2D Modeling

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.

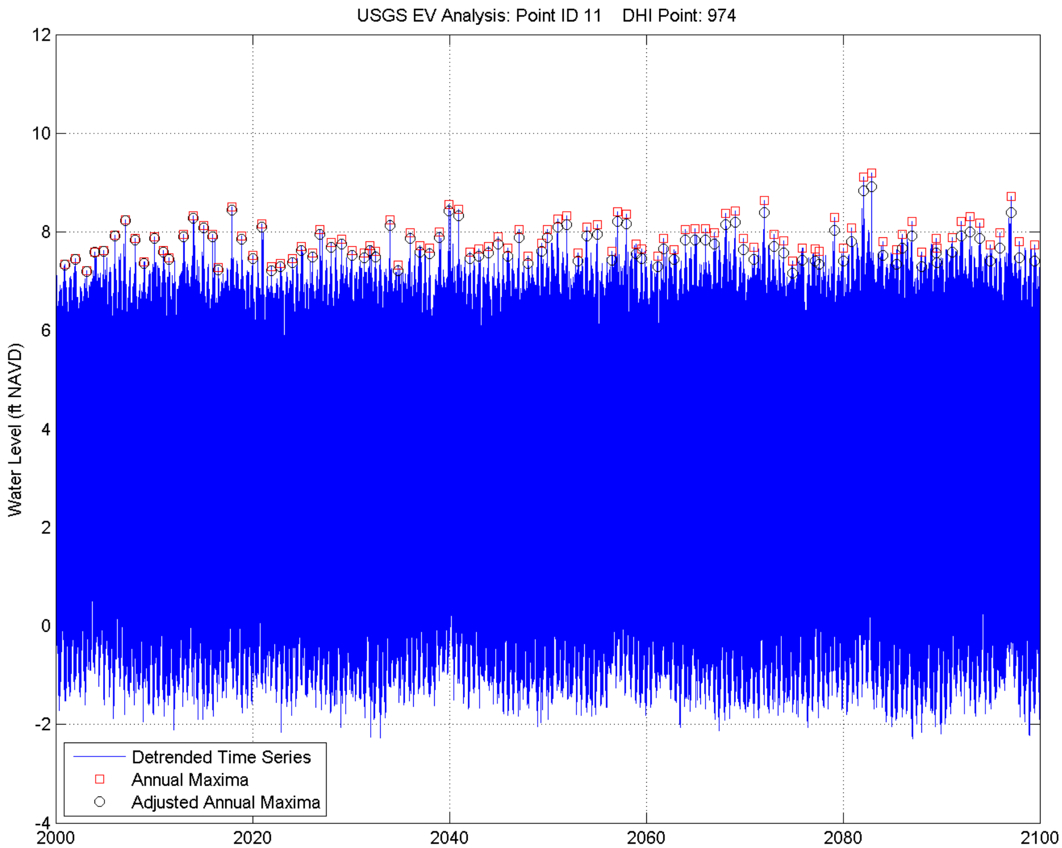


Figure B4.11. Extreme Value Analysis of Annual Maxima for Sample Model Extraction Point along Alameda County Shoreline

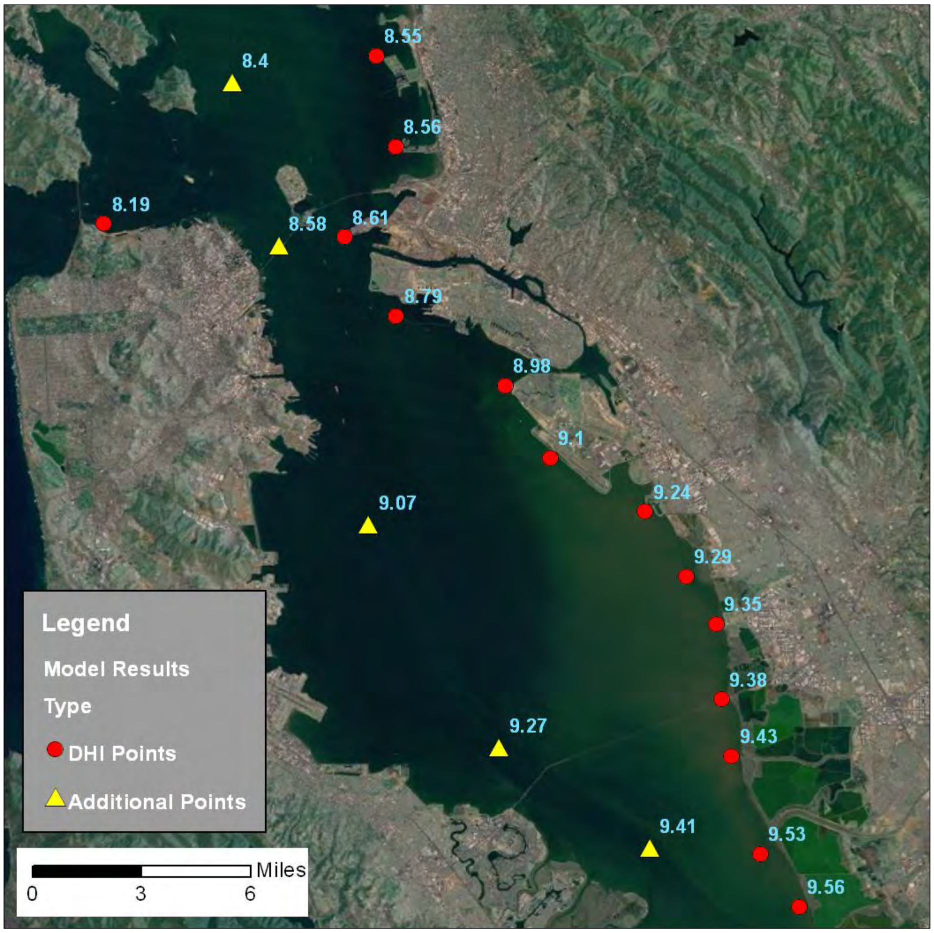


Figure B4.12. Extreme Tide Elevations for Existing Conditions Determined from USGS TRIM2D Modeling

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.

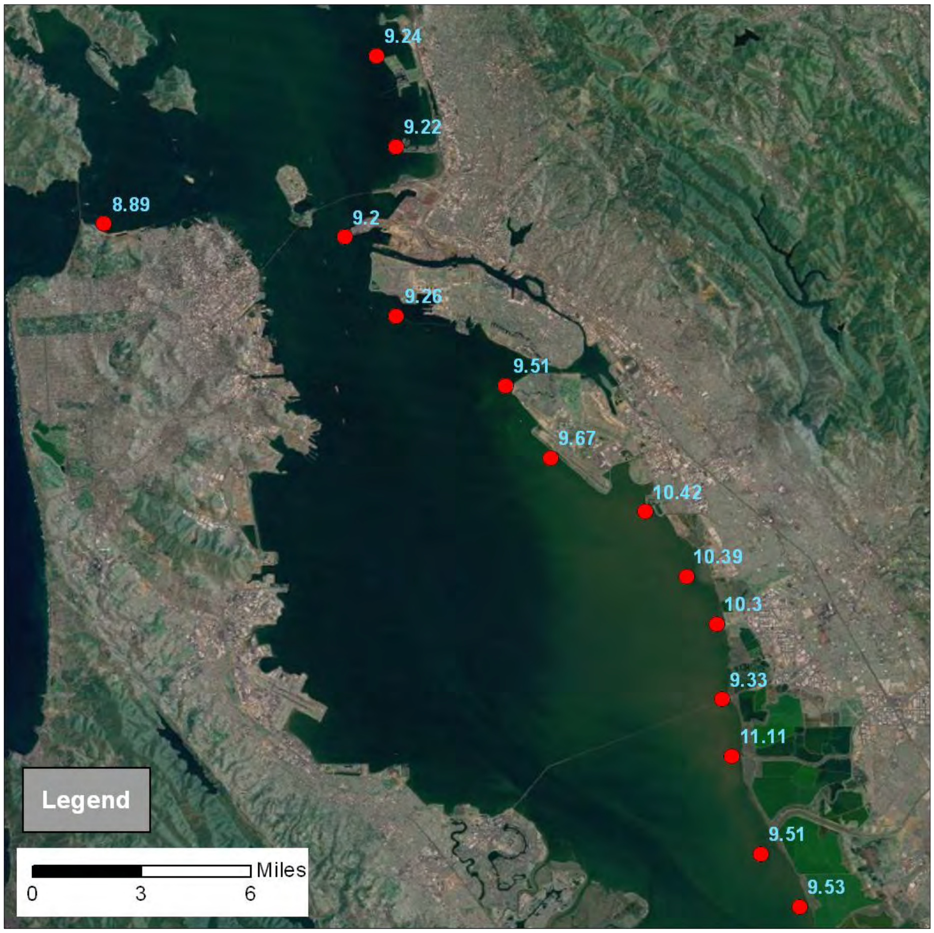


Figure B4.13. Extreme Tide Elevations for Existing Conditions Determined from FEMA MIKE21 Modeling

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.

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.

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

Note: Wave heights shown in units of feet.

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.

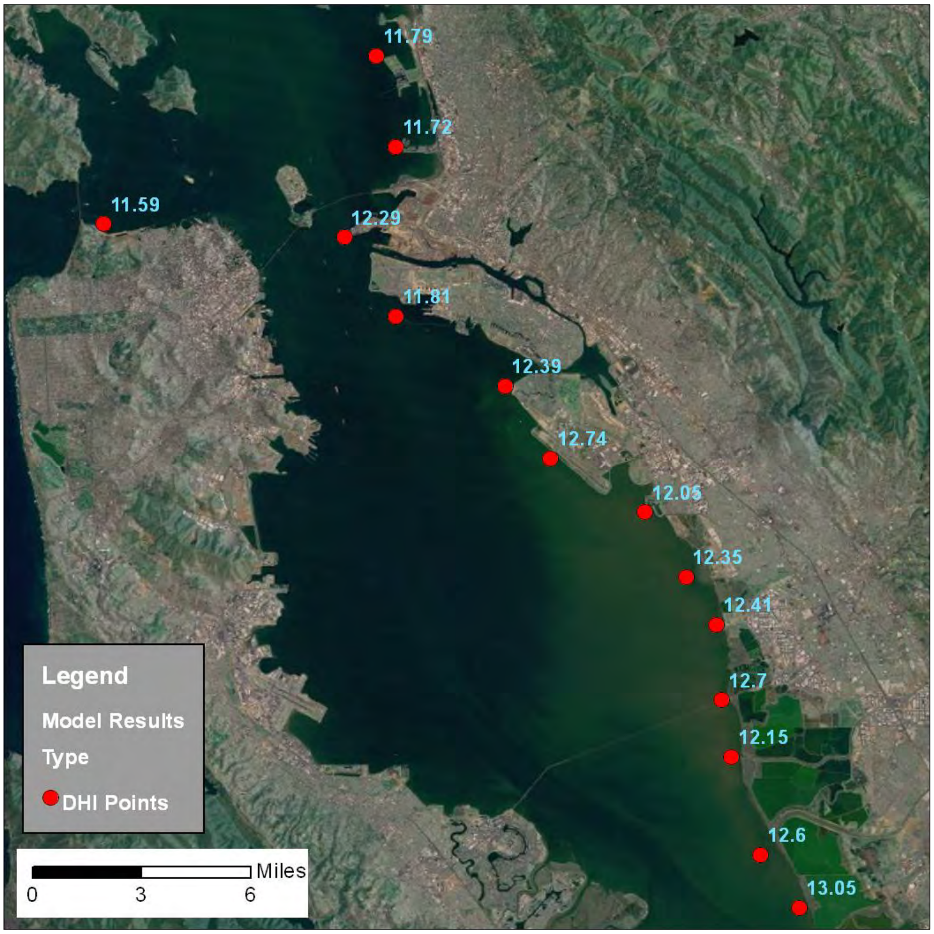


Figure B4.15. Storm Scenario Water Levels with Waves for Existing Conditions

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 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.
- *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 do not take into account inundation due to rainfall or riverine flooding. The maps do not account for inundation associated with changing rainfall patterns, frequency or intensity as a result of climate change.

B4.5 References

Allan, J. C., and P. D. Komar, 2000 (January). *Spatial and Temporal Variations in the Wave Climate of the North Pacific*. Report to the Oregon Department of Land Conservation and Development, Salem, OR.

California Natural Resources Agency. 2009. *2009 California Climate Adaptation Strategy, a Report to the Governor of the State of California in Response to Executive Order S-13-2008*. Available: http://www.energy.ca.gov/2009publications/CNRA-1000-2009-027/CNRA-1000-2009-027-F.PDF.

Cayan, D., M. Tyree, M. Dettinger, H. Hildalgo, T. Das, E. Maurer, P. Bromirski, N. Graham, and R. Flick. 2009 (August). Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment. A Paper from California Climate Change Center, CEC-500-2009-014-F.

Church, J. A., and N. J. White. 2006. A 20th-Century Acceleration in Global Sea Level Rise. *Geophysical Research Letters* 33:L01602.

Conner, K. L. C., D. R. Kerper, L. R. Winter, C. L. May, and K. Schaefer. 2011 (June). Coastal Flood Hazards in San Francisco Bay – A Detailed Look at Variable Local Flood Responses. Proceedings of the 2011 Solutions to Coastal Disasters Conference. Anchorage, AK.

DHI. 2010 (September). *Regional Coastal Hazard Modeling Study for North and Central Bay*. Prepared for Federal Emergency Management Agency.

Federal Highway Administration (FHWA). 2010. Highways and Climate Change: Assessing Vulnerability and Risk of Climate Change Effects on Transportation Infrastructure: Pilot of the Conceptual Model. Available: http://www.fhwa.dot.gov/hep/climate/conceptual_model62410.htm. Accessed April 2010.

Guza, T. T., and E. B. Thornton, 1981. Wave Set-Up on a Natural Beach. *Journal of Geophysical Research* 96:4133–4137.

Hansen, J.E. 2007 (June). Scientific reticence and sea level rise. Environmental Research Letters 2: 024002-024007.

Heberger, M., H. Cooley, P. Herrera, P. H. Gleick, and E. Moore. 2009 (May). The Impacts of Sea Level Rise on the California Coast. A Paper from California Climate Change Center, CEC-500-2009-024-F. Available: http://www.pacinst.org/reports/sea_level_rise/report.pdf.

Intergovernmental Panel on Climate Change (IPCC). 2000. Summary for Policymakers, Emissions Scenarios. A Special Report of IPCC Working Group III. Based on a draft prepared by Nakicenvoic, N., O. Davidson, G. Davis, A. Grubler, T. Kram, E. Lebre la Rovere, B. Mets, T. Morita, W. Pepper, H. Pitcher, A. Sankovski, P. Shukla, R. Swart, R. Watson, and Z. Dadi. 2000. Cambridge: Cambridge University Press.

———. 2007a: Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller. Cambridge University Press, Cambridge, and New York, NY.

———. 2007b. Climate Models and Their Evaluation. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by D. A. Randall, R. A. Wood, S. Bony, R. Colman, T. Fichefet, J. Fyfe, V. Kattsov, A. Pitman, J. Shukla, J. Srinivasan, R. J. Stouffer, A. Sumi, and K. E. Taylor. Cambridge University Press, Cambridge, and New York, NY.

———. 2007c. Regional Climate Projections. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by J. H. Christensen, B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr, and P. Whetton. Cambridge University Press, Cambridge, and New York, NY.

———. 2007d. Global Climate Projections. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by G. A. Meehl, T. F. Stocker, W. D. Collins, P. Friedlingstein, A. T. Gaye, J. M. Gregory, A. Kitoh, R. Knutti, J. M. Murphy, A. Noda, S.C. B. Raper, I. G. Watterson, A. J. Weaver, and Z.-C. Zhao. Cambridge University Press, Cambridge, and New York, NY.

Knowles, N. 2009 (March). Potential Inundation Due to Rising Sea Levels in the San Francisco Bay Region. A Paper from California Climate Change Center, CEC-500-2009-023-F.

———. 2010. Potential Inundation Due to Rising Sea Levels in the San Francisco Bay Region. *San Francisco Estuary and Watershed Science* 8(1).

Madsen, T., and E. Figdor, 2007 (December). When It Rains, It Pours, Global Warming and the Rising Frequency of Extreme Precipitation in the United States. Prepared for the Environment California, Research & Policy Center.

Marcy, D., B. William, K. Draganoz, B. Hadley, C. Haynes, N. Herold, J. McCombs, M. Pendleton, S. Ryan, K. Schmid, M. Sutherland, and K. Waters. 2011 (June). New Mapping Tool and Techniques for Visualizing Sea Level Rise and Coastal Flooding Impacts. Proceedings of the 2011 Solutions to Coastal Disasters Conference. Anchorage, AK,

Mastrandrea, M. D., C. Tebaldi, C. P. Snyder, and S. H. Schneider. 2009. *Current and Future Impacts of Extreme Events in California*. PIER Research Report, CEC-500-2009-026-D, Sacramento, CA: California Energy Commission.

National Aeronautics and Space Administration (NASA). 2009. Satellites Confirm Half-Century of West Antarctic Warming. Available: http://www.nasa.gov/topics/earth/features/warming_antarctica.html. Last updated January 21, 2009.

National Oceanic and Atmospheric Administration, Coastal Services Center (NOAA). 2008. LIDAR 101: An Introduction to LIDAR Technology, Data, and Applications.

National Oceanic and Atmospheric Administration, Coastal Services Center (NOAA). 2011a. Trends in Atmospheric Carbon Dioxide. Earth System Research Laboratory, Global Monitoring Division. Available: http://www.esrl.noaa.gov/gmd/ccgg/trends/global.html#global. Accessed April 2011.

National Oceanic and Atmospheric Administration, Tides and Currents (NOAA). 2011b. Mean Sea Level Trend 9414290 San Francisco, California. Available: http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=9414290. Accessed April 2011.

National Oceanic and Atmospheric Administration, National Weather Service, Climate Prediction Center (NOAA). 2011c. Cold & Warm Episodes by Season. Available: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml. Accessed April 2011.

National Oceanic and Atmospheric Administration U.S. Department of Commerce (NOAA). 2011d. NOAA's El Niño Page. Available: http://www.elnino.noaa.gov/. Accessed April 2011.

National Oceanic and Atmospheric Administration, National Climatic Data Center (NOAA). 2011e. Global Warming, Frequently Asked Questions. Available: http://www.ncdc.noaa.gov/oa/climate/globalwarming.html#q4. Accessed April 2011.

Overpeck, J. T., B. L. Otto-Bliesner, G. H. Miller, D. R. Muhs, R. B. Alley, and J. T. Kiehl. 2006. Paleoclimatic Evidence for Future Ice-Sheet Instability and Rapid Sea Level Rise. *Science* 311(5768):1747–1750. Available: at http://www.sciencemag.org/cgi/content/abstract/311/5768/1747.

Rahmstorf, S. 2007. A Semi-Empirical Approach to Projecting Future Sea Level Rise. Originally published in *Science Express* on December 14, 2006; *Science* 19 January 2007: 315(5810):368–370. DOI: 10.1126/science.1135456.

Raupach, M. R., G. Marland, P. Ciais, C. Le Quere, J. G. Canadell, G. Klepper, and C. B. Field. 2007. Global and Regional Drivers of Accelerating CO_2 Emissions. *Proceedings of the National Academy of Sciences* 104(24):10288–10293.

Rosoff, M. 2011. WATCH: Tsunami Crosses San Francisco Bay. Business Insider article. Available: http://www.businessinsider.com/watch-tsunami-crosses-san-francisco-bay-2011-3. Accessed April 2011.

San Francisco Bay Conservation and Development Commission (BCDC). 2009. Living with a Rising Bay: Vulnerability and Adaptation in San Francisco Bay and on Its Shoreline. April 7, 2009. Available: http://www.bcdc.ca.gov/BPA/LivingWithRisingBay.pdf

San Francisco Planning and Urban Research Association (SPUR). 2011. Climate Change Hits Home. Available: http://www.spur.org/publications/library/report/climate-change-hits-home.

Sea-Level Rise Task Force of the Coastal and Ocean Resources Working Group for the Climate Action Team (CO-CAT). 2010 (October). State of California Sea-Level Rise Interim Guidance Document. Developed with science support provided by the Ocean Protection Council's Science Advisory Team and the California Ocean Science Trust. Available:

http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20100911/14.%20SLR/1011_COPC_SLR_Interim_Guidance.pdf.

Talke, S. A., and M. T. Stacey. 2003. The Influence of Oceanic Swell on Flows over an Estuarine Intertidal Mudflat in San Francisco Bay. *Estuarine Coastal and Shelf Science* 58(2003):541–554. Available: http://superfund.berkeley.edu/pdf/238.pdf.

U.S. Geological Survey (USGS). 1999. El Niño Sea-Level Rise Wreaks Havoc in California's San Francisco Bay Region. USGS Fact Sheet 175-99, Online Version 1.0. Available: http://pubs.usgs.gov/fs/1999/fs175-99/.

———. 2000. Sea Level and Climate. USGS Fact Sheet 002-00. Available: http://pubs.usgs.gov/fs/fs2-00/.

Vermeer, Martin and Stefan Rahmstorf (Vermeer and Rahmstorf). 2009. Global sea level linked to global temperature. PNAS, December 22, 2009, volume 106, number 51. pp 21527-21532.

Walters R.A., Cheng R.T., Conomos T.J. 1985. Time scales of circulation and mixing processes of San Francisco Bay waters. Hydrobiologia 129: p13-36.

This page is intentionally left blank.

Adapting to Rising Tides GIS Exposure Analysis

The aim of this appendix is to familiarize the reader with the data and methodology that was used to conduct an analysis of shoreline and community asset exposure to sea level rise and storm events for the ART project. This analysis was conducted using a Geographic Information System (GIS). GIS is an ideal tool to support sea level rise adaptation planning because it can both perform spatial analyses and produce maps to visualize results. In particular, GIS-based spatial analysis was useful in characterizing the economic, social, and environmental setting of the project area, and in identifying the degree to which assets were exposed to sea level rise and storm events.

Sea Level Rise Inundation Data

To inform an understanding of exposure in the ART project area, a coastal engineering team developed sea level rise inundation maps for six future climate scenarios (AECOM 2011). ART project staff used the resulting maps and underlying data to examine the vulnerability and risk of various assets given the following six scenarios:

- 16" sea level rise + daily high tide (mean high higher water, MHHW)
- 16" sea level rise + 100-year storm (100-year stillwater level)
- 55" sea level rise + 100-year storm with wind waves
- 55" sea level rise + daily high tide (mean high higher water, MHHW)
- 55" sea level rise + 100-year storm (100-year stillwater level)
- 55" sea level rise + 100-year storm with wind waves

The extent and depth of inundation was provided for all the daily high tide and the 100-year storm scenarios. Only the extent of inundation was provided for the 100-year storm with wind waves scenarios because overland wave propagation dissipation processes, which could have a significant effect on inundation depth, were not evaluated. In addition, "disconnected low-lying areas" were identified as areas below the inundated water surface elevation, but not hydraulically connected to the inundated areas due to protection by levees or other topographic features. While these areas would not be flooded, it is important to map them separately because their vulnerability and risk are so closely linked to the condition of the adjacent topographic protection.

Shoreline and Community Asset Data

ART project staff evaluated exposure to sea level rise and storm events for nine of the twelve asset categories (see Table 1). Natural shorelines were evaluated in collaboration with PRBO Conservation Science using their San Francisco Bay Sea-Level Rise Website - Online Decision Support Tool for Tidal Marsh Conservation Planning (http://data.prbo.org/apps/sfbslr/). ART project staff did not evaluate the following categories:

- Community land use: A report on the data and methods used to determine the exposure of the population and household demographics, social vulnerability, jobs, property values, and community services and facilities to sea level rise and storm events is provided as a separate appendix (Heberger and Moore, 2012).
- Seaport: Exposure was not analyzed in GIS, rather a visual assessment of the terminals and rail yards was conducted.
- Structural shorelines: The coastal engineering team performed overtopping potential analysis to assess exposure (AECOM 2011, and see Chapter 2 of this report).

Table 1. Asset categories, data format and sources used in the ART GIS exposure analysis.

Assets Category	Data description	Source	Format	Notes
Airport	Oakland International Airport (runways, terminals and maintenance facilities)			Polygons depicting facility footprints digitized using ESRI World Imagery (2012) and Alameda County Parcel Data
Contaminated Lands	Superfund sites, landfills, leaking underground storage tank sites	US EPA Envirofacts, State Water Resources Control Board Geotracker	Points	
Energy, Pipelines and Telecom	Power plants and substations	California Energy Commission	Points, converted to polygons	Polygons depicting facility footprints digitized using point data, ESRI World Imagery (2012) and Alameda County Parcel Data
	Fuel transmission lines	California Energy Commission	Points, Lines	
Ground Transportation	Railroad alignment	Metropolitan Transportation Commission 2011TeleAtlas	Lines	
	Roadways	Metropolitan Transportation Commission 2011TeleAtlas	Lines	
	BART alignment and stations	Bay Area Rapid Transit	Points, Lines	
	Bus routes	Metropolitan Transportation Commission	Lines	
Hazardous Materials	Hazardous material facilities	US EPA Envirofacts	Points	
Natural Shorelines	Tidal and managed marshes	San Francisco Estuary Institute EcoAtlas	Polygons	Polygons depicting marsh footprints digitized using SFEI EcoAtlas, ESRI World Imagery (2012) and Alameda County Parcel Data
Stormwater Infrastructure	Alameda County flood zones	Alameda County Water Conservation and Flood Control District	Polygons	
	Stormwater pump stations	Alameda County Water Conservation and Flood Control District	Points	
Parks and Recreation	Parks and recreation areas	California Protected Areas Database	Polygons	Polygons depicting the land only portion of park footprints digitized using CPAD and ESRI World Imagery (2012)
Wastewater Facilities	Treatment plants, pump stations, wet weather facilities, dechlorination and discharge facilities, overflow structures, ancillary facilities	East Bay Discharge Authority, East Bay Municipal Utility District, Oro Loma Sanitary District, City of San Leandro	Points, converted to polygons	Polygons depicting facilities were digitized using points data, ESRI World Imagery (2012) and Alameda County Assessor Parcel Data

Analysis Methods

Inundation raster files from AECOM (2011) were used to analyze the exposure of selected assets represented as vectors in point, line, or polygon format (see Table 1) to sea level rise and storm events using ESRI's ArcMap Version 10.0 with the Spatial Analyst extension.

The goal of the analysis was to identify assets that were either totally or partially within inundated areas and to determine the depth of inundation where appropriate. In certain instances this required converting the raster data into polygons using the ArcToolbox Conversion Tool (From Raster to Polygon). Below is an overview of the three data formats and how the data was configured.

Point – A 25-meter (82-feet) buffer using the **AcrToolbox Buffer** tool was created around the point location to approximate the footprint of the asset and to account for any potential spatial error in its exact location. Asset categories with point data included hazardous materials, contaminated lands, and wastewater for example. Using **ArcToolbox Zonal Statistics as Table** tool (Figure 1), assets exposed to each of the inundation scenarios were determined and average depth of inundation computed within the buffered point. Where inundation depth was not determined, i.e., for the storm event with wind wave scenarios and within the low-lying disconnected areas, the Intersect tool was used to determine if assets were exposed.

Line – A 5-meter (16-feet) buffer was created to more accurately depict the footprint of linear assets including the roadways and rail lines. The analysis was conducted in two phases because in creating the buffer the data was converted to a polygon, and it was not possible to calculate the length of the resulting polygon using the **Calculate Geometry** function. Therefore, the initial analysis used **ArcToolbox Intersect** tool (Figure 2) to analyze the overlay between the buffered line data and the inundation data. This analysis determined if the asset was exposed or not as well as the length of asset exposed (e.g., road miles exposed). Where inundation depth was not determined, for example for the storm event with wind wave scenarios and within the low-lying disconnected areas, the Intersect tool was used to determine if assets were exposed.

Polygon – Polygons were used to depicted assets with larger footprints such as parks, wastewater facilities, and tidal marshes. **ArcToolbox Zonal Statistics as Table** tool (Figure 1) was used to determine if the asset footprint was exposed, the portion of the asset footprint exposed, and the average depth of inundation. Where inundation depth was not determined, for example for the storm event with wind wave scenarios and within the low-lying disconnected areas, the Intersect tool was used to determine if assets were exposed.

Recommendations and Considerations

When conducting a multi-sector GIS-based exposure analysis there are a few issues to consider. These include:

- Acquiring, creating and managing geospatial data is time consuming. Allow adequate time to acquire, create and manage GIS data.
- Test a few analytical approaches to find one that is appropriate for the data and is consistent with the project goals. Reach out to peers and GIS experts to troubleshoot problems.
- Structure the data and data output so it can easily be exported into other formats include spreadsheets or databases for use in assessing vulnerability.

Figure 1. Zonal Statistics as Table

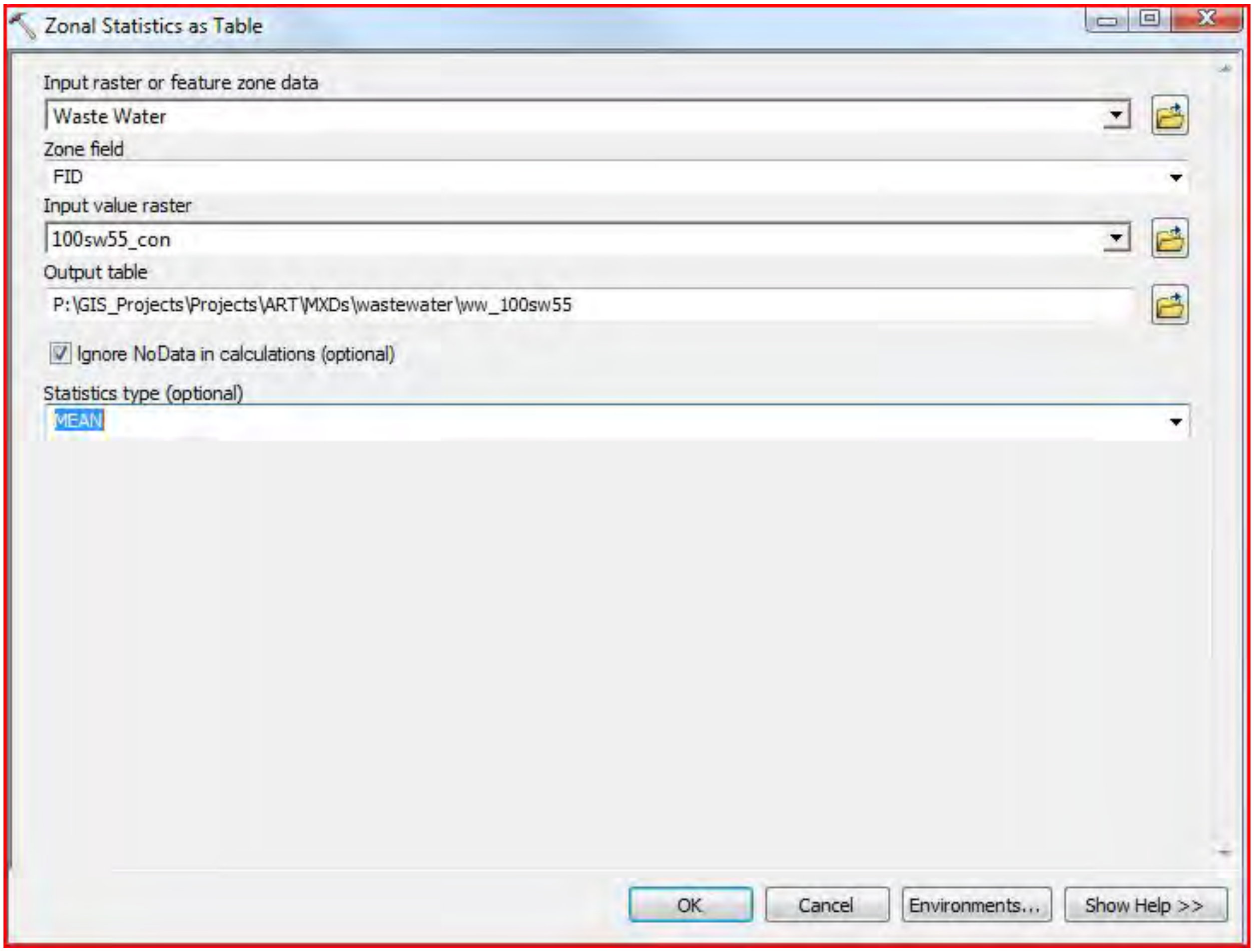
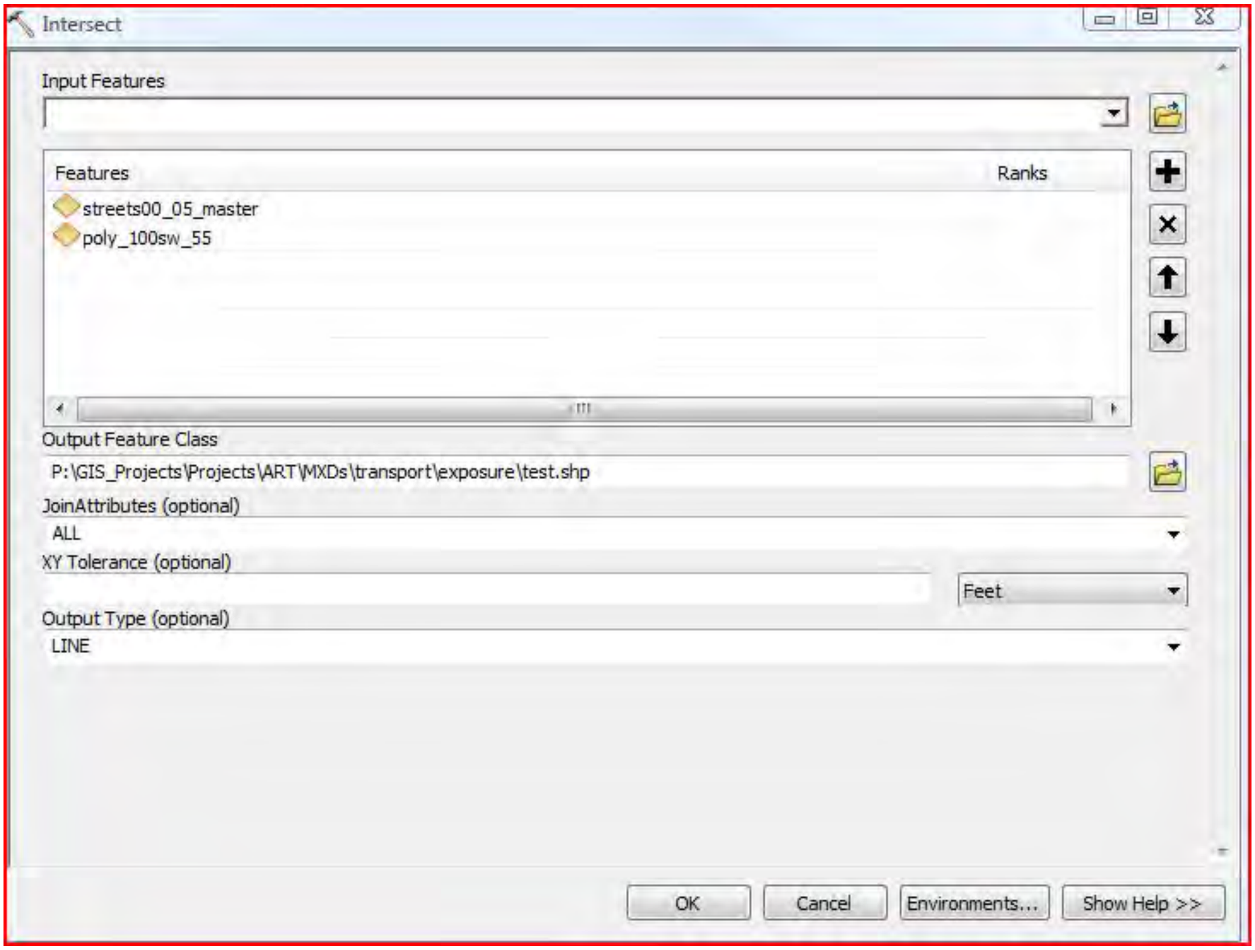


Figure 2. The Intersect Tool



References

Adapting to Rising Tides: Vulnerability to Sea Level Rise in Select Communities in the San Francisco Bay Region. April 12, 2012. Prepared by Matthew Heberger and Eli Moore of the Pacific Institute, Oakland, California.

Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project. November 2011. Prepared by AECOM and Arcadis for the San Francisco Bay Conservation and Development Commission, Metropolitan Transportation Commission and the California Department of Transportation.

Adapting to Rising Tides:
Vulnerability to Sea Level Rise in Select Communities in the San Francisco Bay Region

Prepared by Matthew Heberger and Eli Moore of the Pacific Institute, Oakland, California

For

The San Francisco Bay Conservation and Development Commission

April 12, 2012

Table of Contents

Tables

Figures

1 Introduction

The San Francisco Bay Conservation and Development Commission (BCDC) is working with Bay Area communities to better understand and plan for sea level rise. The Adapting to Rising Tides (ART) project is a partnership with the National Oceanic and Atmospheric Administration Coastal Services Center (NOAA CSC). The Adapting to Rising Tides project is a collaborative effort evaluating how the Bay Area can become more resilient to climate change, in particular sea level rise and storm events. The primary goal of the ART project is to increase the Bay Area's preparedness and resilience to sea level rise and storm events while protecting critical ecosystem and community services. The ART project is a pilot project that will ultimately provide guidance on how best to approach two broad questions:

- How will sea level rise and other climate change impacts affect the future of Bay Area communities, ecosystems, infrastructure, and economy?
- What strategies should we pursue, both locally and regionally, to address these challenges and reduce and manage these risks?

As a part of this project, the Pacific Institute is helping to more closely examine socio-economic vulnerabilities of sea level rise impacts in the ART project area which includes the shoreline communities in Alameda County from Emeryville in the north to Union City in the south. The study area encompasses a portion of Alameda County shoreline from the City of Emeryville to the City of Union City, extending inland approximately a half a mile beyond the area projected to be exposed to storm event flooding with 55 inches of sea level rise.

The Bay Area comprises nine counties that have, according to the 2010 US Census, a population of 7.15 million, or about 1/5 of the state's population. These counties share a connection to nearly 1,000 miles of the San Francisco Bay shoreline. In recent years, the threat of sea level rise has been shown to be real, with potential impacts on residents, the economy, and infrastructure of the Bay Area. Adaptation to climate change and sea level rise are complicated by the fact that 101 cities share responsibility for land use along the San Francisco Bay shoreline (Travis 2009). Because of the size and complexity of the region, the Adapting to Rising Tides project team has chosen to focus on a smaller study area. It is our hope not only that the results of this study will shed light on key issues, but also that the methods illustrated here will be of use to analysts and planners in other areas. The ART study area, shown in Figure 1, is made up of six shoreline cities: Emeryville, Oakland, Alameda, San Leandro, Hayward and Union City, and the unincorporated community of San Lorenzo.

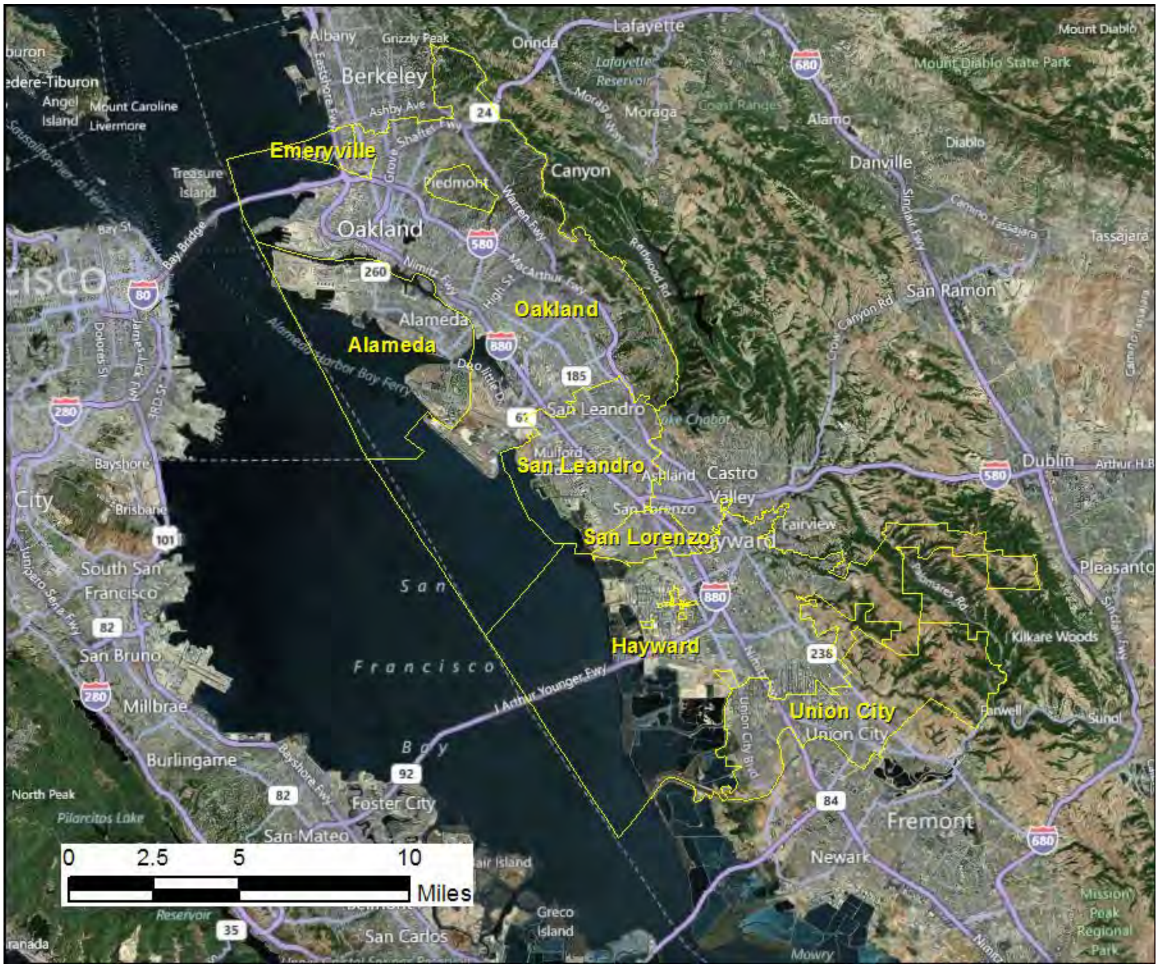


Figure 1 Cities in the ART study area

Previous studies have shown that nearly a quarter million Bay Area residents may be exposed to flooding by the end of the century under a plausible scenario of sea level rise (Heberger 2009; Knowles 2009). Furthermore, there is evidence that the population that could be exposed to flooding is diverse and includes communities with heightened vulnerabilities. Within this group, a significant fraction are low-income, minorities, immigrants who do not speak English well, and those that lack access to transportation.

A priority for the ART project is to develop and test an adaptation planning approach that explicitly identifies equity issues in vulnerability and risk assessments, and integrates consideration of equity into selection of adaptation strategies. Equity issues can underlie the way some communities are disproportionately burdened by the effects of storm events and flooding, which are projected to become more frequent with climate change. While many traditionally disenfranchised communities struggle to get by, flooding associated with climate change will create added challenges, as well as opportunities to build resiliency. Communities that may specifically be vulnerable to natural hazards should also be considered, such as households with no car, less mobile and institutionalized populations. As a cross-cutting issue, equity should be considered across jurisdictions and thematic areas, including public health, emergency response and preparedness, secondary impacts to communities, disaster recovery and adaptation/resilience.

The purpose of the analysis presented in this report is to support the ART project adaptation planning process. Below, we describe a number of analyses that were conducted to assess:

1. Social vulnerability of the populations exposed to SLR in the ART project area
2. Employment and workplace vulnerability
3. Value of the property exposed to SLR in the ART project area
4. Exposure of community assets and liabilities

Following this introduction, Section 2 describes the data and methods used in the Geographic Information System (GIS) analyses and processing of the sea-level rise scenario layers. In Section 3, we estimate the population exposed to inundation risk under each of the sea-level rise scenarios, and analyze the social vulnerability and demographics of the population exposed. The Social Vulnerability Index, or SOVI, developed by Susan Cutter at the University of South Carolina, combines 32 different factors to create a single index of social vulnerability. It includes factors that the literature suggests contribute to a community's ability to prepare for, respond to, and recover from hazards (Cutter et al. 2003). The SoVI index quantifies social vulnerability using available data, mostly from the US Census, including income, race, unemployment, and others. In this study, we use the SoVI index to help understand the social vulnerability of residents in the ART study area and among those exposed to flood risks.

In Section 4, we analyze the workplace vulnerability, tabulating the number of employees that may be exposed to future flooding. In Section 5, we analyze the value of property exposed to inundation risks. We perform the property analysis twice using two different public-domain datasets and compare the results for each method.

In Section 6, we identify which community assets or liabilities may be exposed to future flooding. Assets include critical facilities for emergency response such as police and fire stations, and facilities that deliver social services such as homeless shelters and food banks. Liabilities include areas where toxic materials are stored and have the possibility of being mobilized during a flood.

1.1 A Note about Data and Methods

In this report, we report on each of the four analyses in a separate chapter. Each chapter includes a detailed description of the data, methods, limitations and results. We have attempted to give sufficient detail so that others will be able to repeat this analysis, or perform similar analyses in other cities or regions. We assume the analyst will have experience with GIS, spreadsheets, and databases, and with the use of raster datasets, ESRI's Spatial Analyst, and working with US Census data. We do not attempt to provide a step-by-step tutorial that includes every action required in the analysis; we assume that most analysts undertaking a similar analysis would not benefit from this level of detail. Please contact the authors of this study at the Pacific Institute with any questions or clarification.

1.2 Definitions

Here we define several terms that we use in this report, drawn from Adapting to Rising Tides publications and other sources.

Hazard - The threat of an event that will have a negative effect on people or the environment.

Disaster - The effect of a hazard, that leads to financial, environmental or human losses. To illustrate the difference between a hazard and a disaster, an earthquake is a natural hazard. An earthquake that occurs in an unpopulated area and does not result in damages is not considered a disaster.

Vulnerability - The susceptibility of people, property, and resources to negative impacts from climate change. Vulnerability is a function of the level of exposure to climate change impacts, and the sensitivity and adaptive capacity of the communities and resources that are affected.

Risk - The threat posed by a negative impact or hazard event. The level or degree of risk is the product of the likelihood of an impact occurring and the magnitude of societal, economic, environmental and governance consequences should that impact occur.

Climate Change Adaptation – "Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC 2007).

1.3 Social Vulnerability Overview

Exposure to a flood event can result in a range of harmful physical, economic, and social and psychological effects on the affected population. Studies have also shown that socio-economic conditions of the affected population shape or influence these effects and cause them to be disproportionately severe for certain social groups. Planners, communities, and decision-makers can make use of this research by incorporating an analysis of social vulnerabilities into climate adaptation and other preparedness efforts. Here we summarize a selection of the literature on this topic as background for the analyses in this report.

Those with low incomes are particularly vulnerable to disasters in a number of ways, and for a variety of reasons. They are often under-insured, and more likely to have a home that is damaged in a disaster due to lower quality construction (Fothergill and Peek 2004; Bolin and Bolton 1986; Blanchard-Boehm 1997). During emergency response, studies have found that the poor are one of the groups most likely to not have their needs met (Fothergill and Peek 2004). Further, those with low incomes are more likely to suffer emotional stress and other psychological impacts after a disaster (Fothergill and Peek 2004 citing Bolin and Bolton 1986 and Bolin 1993). Additionally, they may not have the resources, such as car ownership and access to public transit, to evacuate when a disaster hits (Bolin and Bolton 1986; Blanchard-Boehm 1997 cited in Heberger et al. 2009; Brodie et al. 2006).

Besides poverty, age and other socio-economic factors are commonly associated with increased vulnerability to a disaster. Multiple studies have found people of color and ethnic minorities to be particularly vulnerable to disasters (Hajat et al. 2003; Blanchard-Boehm 1997; Perry and Mushkatel 1986; Phillips and Ephraim 1992). Women (who are disproportionately poor), the elderly (who often live on fixed incomes), and children are also vulnerable groups (Hajat et al. 2003). Those who are disabled or have a disabled family member are also more vulnerable, as disabilities can make evacuation more difficult (Hajat et al. 2003; Brodie et al. 2006). Social and geographic isolation are also factors in how people are impacted by a disaster. Wang and Yasui (2008) note that "many recent disaster response crises illustrate how language barriers, isolation from public agencies, and fear of interacting with public agencies combine to increase the vulnerability of many residents."

Finally, institutionalized populations, such as those in hospitals, nursing homes and prisons are reliant on the preparedness and response of the facility, and many post-disaster analyses have found flaws in the disaster preparedness and evacuation planning of institutions (Moser and Ekstrom 2010; Caruson and MacManus 2008).

2 Sea Level Rise and Flood Exposure

For this study, we conducted four separate but related analyses. Here we describe the analytical methods for generating the data on the flood exposure area, and the software and overarching methods that apply to the subsequent four analyses.

2.1 Software

2.1.1 GIS

The bulk of our analysis was performed using Geographic Information Systems (GIS) software. We used ArcGIS Desktop versions 9 and 10. This is commercial software sold by ESRI, a company in Redlands, California. It is among the most widely-used GIS packages. There are free and open-source alternatives that are available, such as qGIS, GRASS, and others. We do not have experience with these packages, however, and cannot say whether they are suitable for performing the range of analyses described below. Any GIS software requires some specialized skill and training to use effectively.

In addition to the basic software, ArcGIS Desktop, the Spatial Analyst extension is required for performing analyses on the raster (grid) flood layers.

We offer the following advice for performing similar analyses. Before committing to performing an operation on a large dataset, experiment with a small dataset. Do not assume that because the operation finished without error that the results are what you wanted. Examine your results periodically by opening the new data layer in a map; examine it by using the identify tool, select tool, opening the attribute table, etc. According to ESRI trainers (Honeycutt et al. 2010), "overlaying large datasets is CPU and RAM intensive." They offer the following advice for performing overlay operations:

- Schedule large overlays accordingly (i.e., lunch, after hours)
- Shut down all other applications
- Use computers with lots of memory

For operations that must be repeated several times (for example, for multiple inundation layers), ArcGIS has built in tools to partially automate some of these procedures. In ArcGIS 9, commands can be run via the Command Line, or in ArcGIS 10, commands can be run via the Python window. We found that it was simple to copy a command from the Results window, change the name of the target input and output files in a text editor, and paste the new command into the Python window. This was generally faster than it would have been to create a custom model in Model Builder or to write a custom Python script to loop over the six files. However, if we were dealing with fifty files rather than six, a custom script would have likely saved time.

2.1.2 Database and Data Analysis

We used Microsoft Access to store several large datasets. The main advantage to using Access is that it can be accessed from both ArcGIS and Microsoft Excel. For example, ArcGIS 9 and 10 can create and edit geographic features in a format that ESRI calls a "personal geodatabase" or PGDB. A personal geodatabase file is a Microsoft Access 2003 database (.mdb) file.

We found these files to have advantages over the newer "file geodatabase" format, because they can be opened directly with MS Access. This means that you can create your own queries in Access to summarize or update the data, which is often faster and easier than using ArcGIS commands. Most importantly, tables can also be accessed from Microsoft Excel via the "Import Data" or "Connect to Data Source" feature. This is useful for summarizing large datasets using Excel's Pivot Table feature.

2.2 Data

In this section, we describe the datasets that were common to several of the analyses. The GIS data layers that we used to estimate the extent of inundation hazard zone within the project area are listed in Table 1 and described below.

Table 1 Data sources for defining flood risk areas

Data layer	Source
Parcels	Alameda County Assessor's Office
Census Block Boundaries	US Census Bureau
Census Block Group Boundaries	US Census Bureau
Census Tract Boundaries	US Census Bureau
Inundation Depth rasters	AECOM
MHHW + 16"	
MHHW + 55"	
100-year Stillwater + 16"	
100-year Stillwater + 55"	
100-year + wind + waves + 16"	
100-year + wind + waves + 55"	

2.2.1 Areas Possibly Exposed to Future Inundation

In order to conduct an exposure assessment, we required a geographic data layer that represents the area possibly exposed to future flooding under a given scenario of sea level rise. These datalayers were developed from 2011-2012 by AECOM, and engineering consulting firm, under contract with BCDC. A more detailed description of the data and methods for creating these datalayers is available in the consultant report (AECOM 2012). The analysis covered three floodwater elevations:

- Mean Higher High Water (MHHW): A standard measure of high tide that occurs on average once a day. NOAA defined MHHW as "the average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch" (NOAA 2000). Higher high water is "the highest of the high waters (or single high water) of any specified tidal day due to the declinational effects of the Moon and Sun."

- 100-year Stillwater: The water level with a 1% chance of occurring in any given year. Stillwater refers to a measurement taken inside a stilling well, which excludes "short period surface waves while freely admitting the tide, other long period waves, and sea level variations." Thus, this measure does not include the effect of wind and waves.

- 100-year Stillwater with Wind and Waves: This is the 1% annual-chance water level including tides, storm surge, and wind and waves. Wind-generated waves can greatly increase the water levels during a storm, causing overtopping of shoreline protection and extensive, however short duration, flooding.

AECOM produced each of these datalayers for both a 16-inch (0.4 m) and 55-inch (1.4 m) sea level rise. These sea level rise scenarios were originally adopted by California's Climate Change Center for climate analysis and planning for the state's Biennial Climate Change Assessment (Heberger 2009). We worked with data files that combined the two SLR scenarios with the three flood elevations, for a total of six files:

- MHHW + 16"
- MHHW + 55"
- 100-year Stillwater + 16"
- 100-year Stillwater + 55"
- 100-year Stillwater + wind + waves + 16"
- 100-year Stillwater + wind + waves+ 55"

For this study, we did not analyze exposure to inundation under current, present-day conditions. However, previous studies (Heberger et al. 2009; Knowles 2009) and current FEMA floodplain maps indicate that the existing flood risk is high in some parts of the Bay Area. As has been often argued, our society is not well adapted to current climate; much less so to future climate. For future studies, it would be worthwhile to analyze present-day hazards as well. This allows us to analyze how much of the future flood risk represents an increase over present-day levels.

2.2.2 Coordinate Systems

We performed a series of analyses in GIS that fall in the category of "overlay analysis." This allowed us to answer the question, "Which features in the study area are exposed to floodwaters under each scenario?" In order to perform such analyses, the input datasets must share a common coordinate system.

Prior to running the analyses, we re-projected all of the GIS datalayers into a common coordinate system. At the suggestion of BCDC staff, we chose a standard projection for Northern California: "NAD 1983 California Teale Albers." The coordinate system is defined by the following parameters:

Projected Coordinate System:	NAD_1983_California_Teale_Albers
Projection:	Albers
False_Easting:	0
False_Northing:	-4,000,000
Central_Meridian:	-120
Standard_Parallel_1:	34
Standard_Parallel_2:	40.5
Latitude_Of_Origin:	0
Linear Unit:	Meter
Geographic Coordinate System:	GCS_North_American_1983
Datum:	D_North_American_1983
Prime Meridian:	Greenwich
Angular Unit:	Degree

2.2.3 Pre-Processing Steps

We should state right off that the analysis required some trial and error. Because of the large size of the inundation data files (each flood raster is about 1 GB in size), not all of the ArcGIS tools worked as expected. We found ourselves patiently waiting over an hour for a process to continue only to be confronted with an error message saying “Out of memory.” The procedures described in this document work reliably but require a number of steps to complete.

We had to first transform the flood layers into a simpler format which occupies less space on disk and can be used with our computers’ available memory. We experimented with creating vector polygon files from the inundation layers. We had success with using the vector-based analysis tools for this type of analysis in the past. However, we were not able to use ArcGIS tools to process these vector layers. We believe that this is due to the large number of vertices contained by some of the polygon features.

We found that the inundation rasters contained more information than was strictly necessary to perform the analysis. The flood depth was stored as a double-precision floating point number, which translates to 15–17 significant decimal digits precision. This level of precision is not warranted by the input data or the analysis methods, neither of which carry this level of precisions, so simplifying the data will not greatly affect our results. Note that we did not “downsample” the raster; we maintained the 2 foot grid cell size throughout the analysis. Rather, we converted the data value contained in each grid cell from a floating point number to a Boolean (true/false) value. The grid cells of the new layers contained a value of either 1 (inundated) or 0 (not inundated). Converting the raster datasets from double-precision to Boolean, as shown in Figure 2, made the files 99.3% smaller (Table 2), and allowed us to run ArcGIS geoprocessing tools on a desktop computer.

Table 2 Raster formats for inundation hazard zones

Raster Format	Example Value	Size on Disk
Double-precision floating point number	2.23498123876541321	1 GB
Integer	2	10 MB
Boolean	1	7 MB

Converting the inundation layers to Boolean also facilitated our analysis of the question, “Is a particular feature inside or outside of the inundation zone?” or “What percentage of an area is inundated?” Using these layers, we cannot answer the question, “What is the depth of inundation for a structure?” Other researchers have shown that it is difficult to assess flooding depth for structures via a desktop study. Generally, digital terrain data does not give sufficient information, and accurate site surveys are needed to determine the elevation of a particular structure (see for example Heinz Center 2000).

Figure 2 Comparison of flood depth layer (left) with binary flood layer (right).

Care was taken to use a consistent naming scheme throughout the project to avoid confusion. Files and database fields representing the various inundation layers were named as shown in Table 3.

Table 3 Naming convention for files and database fields associated with the six inundation scenarios

Inundation Scenario	Flood Percentage Naming Convention	Boolean (True/False) Flood Naming Convention
MHHW + 16”	fld_mhhw16	b_mhhw16
MHHW + 55”	fld_mhhw55	b_mhhw55
100-year Stillwater + 16”	fld_sw16	b_sw16
100-year Stillwater + 55”	fld_sw55	b_sw55
100-year + wind + waves + 16”	fld_ww16	b_ww16
100-year + wind + waves + 55”	fld_sw55	b_sw55

3 Population, Demographics, and Social Vulnerability

This section estimates the population exposed to inundation under each sea-level rise scenario, and the demographics and social vulnerability of the affected population. The analysis provides answers to the following questions:

- How many people are exposed to flooding under each inundation scenario?
- What are the demographics of this population?

- Which areas exposed have populations with social characteristics that increase their vulnerability to potential harm?
- In the most vulnerable areas, what are the specific vulnerabilities that contribute the greatest amount to the population's social vulnerability?

For adaptation measures to protect all populations from sea-level rise, the vulnerabilities of the population potentially exposed must be considered and integrated into planning decisions. The impact of sea-level rise on exposed populations will be more or less severe depending on various socio-economic conditions. The diverse and complex relationships shaping social vulnerability cannot be predicted with complete certainty, but studies have identified specific factors and methods for quantifying the relative social vulnerability within populations. Foremost among these is the Social Vulnerability Index (SoVI), which we use to estimate the overall relative social vulnerability of local communities within the study area.

SoVI is a methodology increasingly used in planning to account for the socio-economic conditions that influence population vulnerability to a range of hazards, including hurricanes, flood events, and others. SoVI compiles datasets from the US Census and creates a 'score' for each block group indicating the local population's degree of social vulnerability. The National Oceanic and Atmospheric Administration (NOAA) has published complete datasets of SoVI analysis results for all block groups in coastal US states. The following methodology utilizes the NOAA data and additional US Census data.

3.1 Data

We used two sources of data for population, households, and demographics, both obtained online from public sources. To estimate the total population exposed, we used US Census data on households and total population at the census block level. For social vulnerability and population demographics, we used a composite indicator of Social Vulnerability published by NOAA that aggregates 31 variables and is compiled at the Census Block Group level (NOAA CSC 2011). Table 4 lists all population data used.

A household is defined by the Census Bureau as "all the persons who occupy a housing unit. A housing unit is a house, an apartment, a mobile home, a group of rooms, or a single room." In the study area, there is an average of 2.6 people per household. The Census Bureau classifies people not living in households are classified as living in *group quarters*. We consider some populations in group quarters as especially vulnerable, for example those in prisons or nursing homes, while others may not have especially heightened vulnerability, such as college students living in dormitories. We analyze exposure of those in group quarters in more detail in Section 6, Community Assets and Liabilities Exposed to Flood Risk.

Table 4 Datasets and their sources for population characteristics contributing to social vulnerability

Boundary Files	
Census Block Boundaries	US Census Bureau, 2009
Census Block Group Boundaries	US Census Bureau, 2009
Census Block Tables	
Total population	US Census, 2000
Households	US Census, 2000
Census Block Group Tables	
Social Vulnerability Index (SoVI) Score	NOAA/USC, 2011
Percent African American	NOAA/USC (2000 Census)
Percent Native American	NOAA/USC (2000 Census)
Percent Asian and Hawaiian Islander	NOAA/USC (2000 Census)
Percent Hispanic	NOAA/USC (2000 Census)
Percent of population under 5 years of age	NOAA/USC (2000 Census)
Percent of population age 65 and over	NOAA/USC (2000 Census)
Median age	NOAA/USC (2000 Census)
Percent female population	NOAA/USC (2000 Census)
Average number of people per household	NOAA/USC (2000 Census)
Percent renter occupied units	NOAA/USC (2000 Census)
Percent female headed households, no spouse present	NOAA/USC (2000 Census)
Nursing home residents per capita	NOAA/USC (2000 Census)
Percent civilian unemployment	NOAA/USC (2000 Census)
Per capita Income (2000 dollars)	NOAA/USC (2000 Census)
Percentage of households earning 100,000 or more	NOAA/USC (2000 Census)
Percent living below the poverty level	NOAA/USC (2000 Census)
Mean House Value	NOAA/USC (2000 Census)
Mean contract rent for renter occupied housing units	NOAA/USC (2000 Census)
Number persons per 100,000 population employed as healthcare practitioners and technical occupations	NOAA/USC (2000 Census)
Percent rural farm population	NOAA/USC (2000 Census)
Percent of housing units that are mobile homes	NOAA/USC (2000 Census)
Percent of population 25 years or older with no high school diploma	NOAA/USC (2000 Census)
Percent of population participating in the labor force	NOAA/USC (2000 Census)
Percent females participating in the labor force	NOAA/USC (2000 Census)
Percent employment in farming, fishing, and forestry occupations	NOAA/USC (2000 Census)
Percent employed in transportation, communications, and other public utilities	NOAA/USC (2000 Census)
Percent Employed in service industry	NOAA/USC (2000 Census)
Percent of population collecting social security benefits	NOAA/USC (2000 Census)

Percent Foreign Born Citizens Immigrating between 1990 and 2000	NOAA/USC (2000 Census)
Percent urban population	NOAA/USC (2000 Census)
Housing Density	NOAA/USC (2000 Census)
Linguistically isolated households	US Census, 2000
Households with no vehicle	US Census, 2000
People of color (non-white, non-Hispanic)	US Census, 2000
Households in poverty (earning less than 200% of the national poverty level)	US Census, 2000
Renter-occupied households	US Census, 2000
Population living in “group quarters”	US Census, 2000

The Census Bureau has published population data from the 2010 Census. However these data are aggregated according to new geographic boundaries that are different from, and not compatible with, data from the 2000 Census. Because of the changing Census boundaries between 2000 and 2010, we chose to use total population data from the 2000 Census. The boundaries of Census blocks were updated with the 2010 Census, adjusting the geographic area covered by some blocks and creating nearly 3 million new Census blocks in the country (US Census Bureau 2011). This prevents the reliable integration of 2000 and 2010 datasets for Census blocks and block groups. Therefore, our analysis does not include data from the 2010 Census.

For the break-down of different social groups, demographic data from the 2000 Census rather than the American Community Survey was used. Data on local demographics is available from the 2005–2009 American Community Survey (ACS), but due to the sampling methods of the ACS, this data is often suppressed or has high margins of error at the block group level. Using demographic data from higher levels, such as Census tracts, is unreliable due to the heterogeneous population and large geographic areas within tracts. For these reasons, we recommend using demographic data from the 2000 Census until a more recent dataset with high reliability at the block group level has been released.

3.2 Methods

Methods for estimating population exposed and social vulnerability involve four steps:

1. Calculate percentage of area inundated for all blocks in study area
2. Estimate population exposed to inundation for all bocks, and sum block population exposed up to the block group level
3. Append demographic data and sort block group population exposed into categories of social vulnerability
4. Estimate demographics of population exposed, and identify key vulnerabilities of population with high overall social vulnerability

Estimating population exposed at the *block* level rather than at the level of the *block group* is an important aspect of this methodology. Steps 1 and 2 are described in section 3.2.1 below and utilize *block* level data. Steps 3 and 4 are described in section 3.2.2 below and utilize *block group* level data.

3.2.1 Population Exposed to Flooding

We clipped Census block boundaries (US Census 2009) to remove water bodies from Block Group areas. This step was necessary because many census blocks have boundaries extending far out into the Bay, and with this geometry it is not possible to calculate the area of formerly dry land that would be inundated by a flood layer. The 2009 Census block boundary files include only the blocks from the 2000 Census, but the boundaries have been updated to more accurately reflect the roads, waterways, and other reference points for block boundaries.[1] For each Census block in the study area, we calculated the percent area inundated using the methods described in Appendix D.

The result of the procedure described in Appendix D is a table with the percent area inundated for each Census block in the study area. Multiplying the percent area inundated by the total block population generates a figure for population exposed to inundation. Next the figures for block population exposed are summed to the block group level using the attribute column noting the block group identification number for each block. The same is done for the block households exposed. We did this step by exporting the attribute table to Excel and using the Excel Pivot Table tool to sum block population and households exposed to the block group level.

3.2.2 Social Vulnerability of Population Exposed

The SoVI score for all block groups in Coastal US states have been calculated and published by the National Oceanic and Atmospheric Administration (NOAA) in partnership with the University of South Carolina. The SoVI dataset from NOAA for California uses Census 2000 data for analyzing 31 variables to calculate index scores at the Census block group level (NOAA 2011). Shapefiles with SoVI scores for block groups within a coastal state can be downloaded from the NOAA Data Access Viewer link at http://www.csc.noaa.gov/digitalcoast/data/SoVI/. The methodology used to calculate SoVI scores was first published and has been refined by Susan Cutter and the Hazards and Vulnerability Research Institute at the University of South Carolina (Cutter 2003, Cutter et al 2009). For a list of all variables included in the SoVI scoring methodology used in the NOAA dataset, see Table 5.

Table 5 Variables included in the composite Social Vulnerability Index

Variable	Label in Data Files	Relation to vulnerability
Percent African American	QBLACK	Positive
Percent Native American	QINDIAN	Positive
Percent Asian and Hawaiian Islander	QASIAN	Negative
Percent Hispanic	QSPANISH	Positive
Percent of population under 5 years of age	QKIDS	Positive
Percent of population age 65 and over	QPOP65O	Positive
Median age	MEDAGE	Negative
Percent female population	QFEMALE	Positive
Average number of people per household	PPUNIT	Positive
Percent renter occupied units	QRENTER	Positive

[1] TIGER/Line Shapefiles and TIGER/Line Files. Retrieved from http://www.census.gov/geo/www/tiger/shp.html

Variable	Label in Data Files	Relation to vulnerability
Percent female headed households, no spouse present	QFHH	Positive
Nursing home residents per capita	NRRESPC	Positive
Percent civilian unemployment	QCVLUN	Positive
Per capita Income (2000 dollars)	PERCAP	Negative
Percentage of households earning 100,000 or more	QRICH	Negative
Percent living below the poverty level	QPOVTY	Positive
Mean house value	MEAN_HSEVA	Negative
Mean contract rent for renter occupied housing units	MC_RENT	Positive
Number persons per 100,000 population employed as healthcare practitioners and technical occupations	PHYSICN	Negative
Percent rural farm population	QRFRM	Positive
Percent of housing units that are mobile homes	QMOHO	Positive
Percent of population 25 years or older with no high school diploma	QED12LES	Positive
Percent of population participating in the labor force	QCVLBR	Negative
Percent females participating in the labor force	QFEMLBR	Positive
Percent employment in farming, fishing, and forestry occupations	QAGRI	Positive
Percent employed in transportation, communications, and other public utilities	QTRAN	Positive
Percent Employed in service industry	QSERV	Positive
Percent of population collecting social security benefits	QSSBEN	Positive
Percent Foreign Born Citizens Immigrating between 1990 and 2000	QMIGRA	Positive
Percent urban population	QURBAN	Positive
Housing Density	HODENSTY	Negative

The detailed methodology for calculating SoVI scores is re-printed in Appendix A as a reference. This is a useful reference, but most analysts will not need to learn the details, as SoVI scores have already been calculated for all block groups in California by NOAA's Coastal Services Center (CSC). For more information on SoVI methods, see the online document, "HVRI Frequently Asked Questions" (HVRI 2011). In brief, calculating SoVI scores involves following the seven steps below.

1. Collect the data for each variable and normalize all variables as either percentages, per capita values, or density functions
2. Verify accuracy of the dataset using descriptive statistics
3. Standardize the input variables using z-score standardization
4. Perform a principal components analysis (PCA) to reduce the tendency for a variable to load highly on more than one factor.
5. Adjust the cardinality (positive or negative) of the variables so that the signs of the subsequent defining variables are appropriately describing the tendency of the phenomena to increase or decrease vulnerability
6. Place the components in an additive model and sum to generate the overall SoVI score for the place

7. Map SoVI scores using an objective classification (i.e. quantiles or standard deviations) with 3 or 5 divergent classes so illustrate area of high, medium, and low social vulnerability.

We joined the Census block group data table (containing data on population and number of households) with the table containing SoVI scores and the flood percent table described in the previous section. The join is based on the Census block group FIPS code, which is a 12-digit unique identifier (see Figure 12 on page 73 for more information on FIPS codes). This allowed us to calculate the population and households exposed to flooding in each block group under each of the six scenarios. There are a number of ways to perform a table join. We used the VLOOKUP function in Excel with the block group FIPS codes as the join field joins the two tables. Once the tables are joined, the block groups can be sorted according to their SoVI score. We also used SQL queries within MS Access to double-check the results of our calculations.

With the population exposed and the SoVI scores in one table, the block groups were broken into three groups according to their SoVI scores. Based on the SoVI scores for all block groups in Alameda County, three categories were created with scores below the 33rd percentile considered “Low Vulnerability,” those between the 33rd and 66th percentile considered “Medium,” and the higher third comprising “High Vulnerability.” Basing categories on all block groups in the county allows the analysis to compare the vulnerability of flood-exposed areas to all areas in the county. Breaks at the 33 and 66th percentile SoVI score in Alameda County are shown in Table 6.

Table 6 Breaks for ranking social vulnerability into bins

Social Vulnerability	SoVI Scores
Low	–8.181 to –0.0384
Medium	–0.0385 to +2.450
High	+2.451 to +12.364

In Table 7, we report the population in blocks by social vulnerability rank and by city. Nearly half (48%) of the population in the 7 study-area cities lives in Census block groups with a high social vulnerability rank. Note that there are a small number of block groups in the study area for which a SOVI score has not been calculated. These areas are largely commercial or industrial, and have a small population, thus there was probably not enough information to compile the SOVI score for these block groups.

Table 7 Population in Block Groups, by Social Vulnerability Rank and by City

	Low	Medium	High	Missing	Total
Alameda	18,006	32,972	21,281	-	72,259
Emeryville	3,867	759	2,256	-	6,882
Hayward	16,907	91,257	31,866	-	140,030
Oakland	58,615	67,946	272,918	5	399,484
San Leandro	4,240	42,826	32,386	-	79,452
San Lorenzo		18,602	3,296	-	21,898
Union City	10,913	38,747	17,209	-	66,869
Total	112,548	293,109	381,212	5	786,874
	14%	37%	48%	0%	100%

To estimate the absolute numbers of people in socially vulnerable groups, data from the NOAA SoVI dataset on social variables can be used, or new tables of Census block group data can be integrated. If the social variable of interest is in the SoVI dataset, the percentage with a chosen variable of vulnerability (e.g. percentage of population under age five) is multiplied by the population exposed to flooding in a sea-level rise scenario. If the social vulnerability variable is not in the SoVI dataset, a new table can be downloaded from the census for block groups in the study area, and joined to the existing table using the block group FIPS codes.

Additional datasets of socially vulnerable populations outside of SoVI were compiled to analyze the absolute numbers of several populations known to have increased vulnerability to environmental hazards. These include:

- Households with limited English (no member over age 14 identifies as speaking English 'well')
- Households with no vehicle
- People of color (non-white, non-Hispanic)
- Households in poverty (earning less than 200% of the national poverty level)
- Renter-occupied households
- Population living in "group quarters", including institutions like correctional facilities, nursing homes, and mental hospitals, college dormitories, military barracks, group homes, missions, and shelters.

3.3 Limitations

Our estimates of the number of people affected were based on current population figures, as reported in the US Census. Our analysis did not use population projections because these projections are not available below the county level. The actual rate and distribution of population growth, and social and economic change will play a key role in shaping vulnerability in the future. As reported in Table 8, the region experienced modest population growth over the past decade. Every city added to its population except Oakland, which experienced a slight decline. The greatest percent growth occurred in Emeryville, where population grew by 46% over 10 years.

Table 8 Cities in the Adapting to Rising Tides study area and their population in 2000 and 2010

City	2000 Population	2010 Population	10-year Change	Percent Change
Alameda	72,259	73,812	+ 1,553	2%
Emeryville	6,882	10,080	+ 3,198	46%
Hayward	140,030	144,186	+ 4,156	3%
Oakland	399,484	390,724	– 8,760	–2%
San Leandro	79,452	84,950	+ 5,498	7%
San Lorenzo	21,898	23,452	+ 1,554	7%
Union City	66,869	69,516	+ 2,647	4%
Total	**786,874**	**796,270**	**+ 9,846**	**1%**

Certain populations with heightened vulnerability are not well represented in Census datasets. Homeless individuals and families are a particularly vulnerable segment of the population due to their lack of shelter, lack of resources and the difficulty in connecting with services and public agencies. However, local data on the location and size of this population is limited, as it is often changing and the Census only counts homeless people at shelters and pre-selected locations. Alameda County conducts a more comprehensive count of the homeless population every two years, and in 2011 documented 4,178 homeless individuals in the county (Focus Strategies 2011). The data is not broken down by geographic area within the county, preventing a quantitative analysis of those that may be exposed to flooding with projected sea-level rise.

Our analysis summarized social vulnerability at the census block group level, obscuring any variation within block groups. The Census Bureau periodically redraws boundaries so that the population within each tract is relatively homogenous and ranges between 600 and 3,000 residents. However, population changes happen more frequently than adjustments to boundaries, allowing for potentially significant demographic variation within tracts and size differences between tracts. Particularly in coastal areas, there is a chance that the part of a block group adjacent to the shoreline is less populated than areas further inland.

The science of measuring social vulnerability is rapidly developing and the SoVI methodology is still being refined. The variables included in the SoVI index were changed by its creators to reflect new understanding in 2010.[2]

Certain variables in SoVI explain a greater degree of the differences in scores between geographic areas. When the Hazards and Vulnerability Research Institute looked at which variables in the SoVI analysis contributed the greatest amount to the overall score nationally, they found that nine components explained 76% of the variance in the data. These nine components were: socioeconomic status, elderly and children, rural agriculture, housing density, black female-headed households, gender, service

[2] Hazards and Vulnerability Research Institute (2012). Changes and Improvements in the SoVI Formulation. Retrieved March 10th, 2012, from http://webra.cas.sc.edu/hvri/products/sovi_details.aspx

industry employment, unemployed Native Americans, and infrastructure employment.[3] This does not imply, however, that these components are the most important determinant the SoVI score at a local or county level.

3.4 Findings

3.4.1 Land Area Exposed to Flooding

The following set of tables show the area in each study-area city that is vulnerable to inundation, by scenario. These tables are shown for reference; we did not attempt to classify the land cover type that is inundated. Table 9 shows the area exposed to inundation in each city, in square miles. Table 10 shows the percentage of the total land area in each city that is exposed to inundation, by scenario.

Table 9 Land area in square miles exposed to inundation risk for the 6 ART scenarios, by city

	MHHW		100-year Stillwater		100-year + Wind and Waves		Total Land Area in City
	+ 16”	+ 55”	+ 16”	+ 55”	+ 16”	+ 55”	(for reference)
Alameda	0.72	3.48	2.50	6.32	6.37	8.28	10.61
Emeryville	0.02	0.03	0.03	0.20	0.20	0.43	1.23
Hayward	5.60	14.11	13.45	16.23	16.24	17.88	44.56
Oakland	1.46	6.04	4.39	9.80	9.77	12.82	55.85
San Leandro	0.51	1.44	1.14	2.88	2.76	3.79	13.25
San Lorenzo	0.07	0.26	0.21	0.69	0.65	0.99	2.79
Union City	0.55	2.63	1.45	3.80	3.83	5.04	19.47
Total	8.94	27.99	23.15	39.91	39.82	49.22	147.76

Table 10 Percentage of each city's land area exposed to flood risk, by scenario and by city

	MHHW		100-year Stillwater		100-year + Wind and Waves	
	+ 16”	+ 55”	+ 16”	+ 55”	+ 16”	+ 55”
Alameda	7%	33%	24%	60%	60%	78%
Emeryville	2%	3%	2%	16%	16%	35%
Hayward	13%	32%	30%	36%	36%	40%
Oakland	3%	11%	8%	18%	17%	23%
San Leandro	4%	11%	9%	22%	21%	29%
San Lorenzo	2%	9%	8%	25%	23%	36%
Union City	3%	13%	7%	20%	20%	26%
Total	6%	19%	16%	27%	27%	33%

[3] Hazards and Vulnerability Research Institute (2012). “Social Vulnerability Index for the United States - 32 Variables”. Retrieved March 19th, 2012, from http://webra.cas.sc.edu/hvri/products/SoVI_32.aspx.

3.4.2 Population Exposed to Flooding

Depending on the scenario, there are between approximately 2,000 and 123,000 residents currently living in the areas that would be exposed to flooding (Table 11). Under the most extreme scenario, a 55-inch rise in sea levels and a 100-year storm event plus wind and wave scenario, 43,300 households are exposed to inundation. Table 12 shows the percentage of each city's population exposed to inundation risk for each of the six scenarios. Table 13 shows the number of households exposed to flood risk. In each of the tables, results are rounded to whole numbers. However, the reader should keep in mind the approximate nature of the analysis methods do not reflect this level of precision.

Table 11 Population exposed to inundation risk for the 6 ART scenarios, by city

	MHHW		100-year Stillwater		100-year + Wind and Waves		City Population
	+ 16"	+ 55"	+ 16"	+ 55"	+ 16"	+ 55"	(for reference)
Alameda	1,103	14,227	8,619	30,009	30,376	41,461	72,259
Emeryville	29	96	56	725	718	1,909	6,882
Hayward	82	187	167	5,011	4,999	10,620	140,030
Oakland	16	1,370	233	6,107	5,965	14,831	399,484
San Leandro	356	4,246	3,220	10,070	9,447	15,466	79,452
San Lorenzo	13	200	177	2,888	2,628	5,337	21,898
Union City	353	17,940	4,849	25,253	25,501	34,163	66,869
Total	1,952	38,266	17,321	80,063	79,634	123,787	786,874

Table 12 Percentage of each city's population exposed to flood risk, by scenario and by city

	MHHW		100-year Stillwater		100-year + Wind and Waves	
	+ 16"	+ 55"	+ 16"	+ 55"	+ 16"	+ 55"
Alameda	1.5%	19.7%	11.9%	41.5%	42.0%	57.4%
Emeryville	0.4%	1.4%	0.8%	10.5%	10.4%	27.7%
Hayward	0.1%	0.1%	0.1%	3.6%	3.6%	7.6%
Oakland	0.0%	0.3%	0.1%	1.5%	1.5%	3.7%
San Leandro	0.4%	5.3%	4.1%	12.7%	11.9%	19.5%
San Lorenzo	0.1%	0.9%	0.8%	13.2%	12.0%	24.4%
Union City	0.5%	26.8%	7.3%	37.8%	38.1%	51.1%
Total	0.2%	4.9%	2.2%	10.2%	10.1%	15.7%

Table 13 Households exposed to flood risk, by scenario and by city

	MHHW		100-year Stillwater		100-year + Wind and Waves		Total Households
	+ 16"	+ 55"	+ 16"	+ 55"	+ 16"	+ 55"	(for reference)
Alameda	397	5,883	3,557	12,297	12,440	16,830	30,226
Emeryville	21	70	41	512	507	1,329	3,975
Hayward	25	62	54	1,910	1,906	3,568	44,804
Oakland	6	490	120	1,945	1,905	5,394	150,790
San Leandro	112	1,690	1,317	3,702	3,487	5,538	30,642
San Lorenzo	5	70	62	984	896	1,840	7,500
Union City	95	4,533	1,248	6,499	6,566	8,856	18,642
Total	**661**	**12,798**	**6,399**	**27,849**	**27,707**	**43,355**	**286,579**

3.4.3 Social Vulnerability of Population Exposed

Combining the diverse social factors that influence the likelihood of harm during a flood event into a composite score allows for an estimate of the overall level of vulnerability in a local area and a comparison among areas. In this analysis, the block groups in Alameda County are sorted into thirds according to their SoVI score. The population in block groups that are in the top third most socially vulnerable in the county is labeled "high", with "medium" and "low" representing the middle and bottom third.

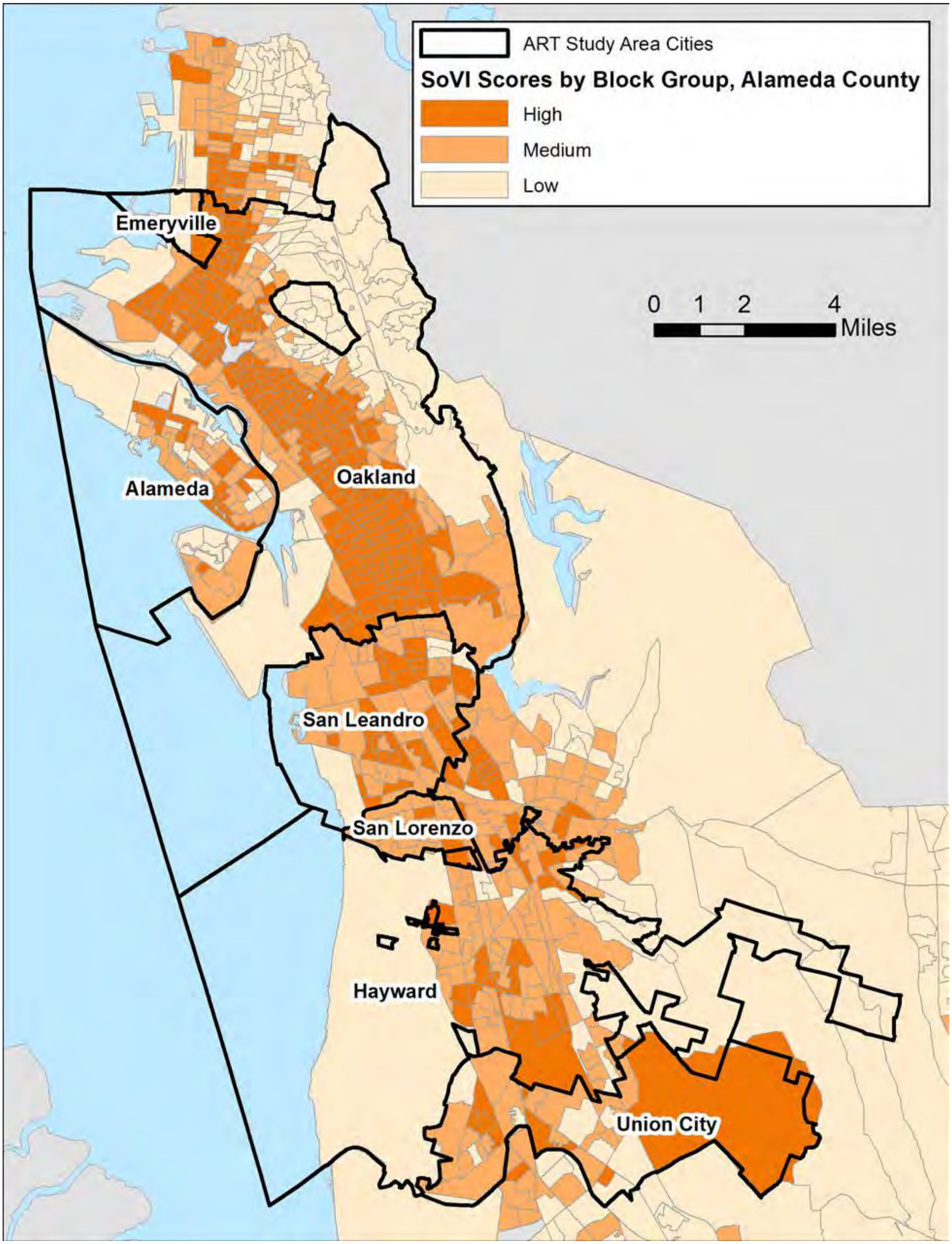


Figure 3 Social Vulnerability Index Score by Block Group in the ART Study Area (Census 2000)

Mapping the social vulnerability scoring clearly displays the distinct social geography of the study area, with more highly vulnerable populations concentrated in the low-land areas (Figure 3). The areas adjacent to the shoreline are somewhat of an exception to this pattern, with a more mixed geography of vulnerability. These areas also have a higher proportion of industrial and commercial areas, which may also contribute to the lower social vulnerability scores.

Table 14 reports exposure to flood risk by level of social vulnerability. Thirty six percent or 44,000 of the people at risk of inundation under the most severe scenario fall within the category of high social vulnerability. An additional 60,000 or 48% are considered in the middle range of social vulnerability. Sorting the population vulnerability into the seven cities in the study area (Table 15) allows us to identify where the more vulnerable population is located. The greatest population percentages with high social vulnerability in flood risk areas occur in Oakland and Hayward. In Alameda and Union City the high vulnerability population does not comprise as high a percentage of the total population at risk, but still comprise significant numbers in absolute terms (11,000 and 9,200 respectively).

Table 14 Population at risk of inundation by level of social vulnerability

	MHHW		100-year Stillwater		100-year + Wind and Waves		Total Population
	+ 16”	+ 55”	+ 16”	+ 55”	+ 16”	+ 55”	(for reference)
High	78	12,100	5,625	27,554	27,309	44,111	381,212
Medium	1,472	19,803	8,104	39,730	39,516	59,871	293,109
Low	402	6,364	3,591	12,780	12,808	19,803	112,548
missing	0	0	0	0	0	0	5
Total	**1,952**	**38,266**	**17,320**	**80,065**	**79,633**	**123,786**	**786,874**
Percentage of population at risk							
High	4%	32%	32%	34%	34%	36%	48%
Medium	75%	52%	47%	50%	50%	48%	37%
Low	21%	17%	21%	16%	16%	16%	14%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Table 15 Social Vulnerability Ranking of Population by City

		MHHW		100-year Stillwater		100-year + Wind and Waves		Population
		+ 16"	+ 55"	+ 16"	+ 55"	+ 16"	+ 55"	(for reference)
Alameda								
	Low	107	3,777	2,648	8,404	8,483	12,470	18,006
	Medium	985	6,866	4,241	13,429	13,619	17,785	32,972
	High	11	3,584	1,730	8,176	8,273	11,206	21,281
	Total	**1,103**	**14,227**	**8,619**	**30,009**	**30,376**	**41,461**	**72,259**
Emeryville								
	Low	29	96	56	725	718	1,909	3,867
	Medium	0	0	0	0	0	0	759
	High	0	0	0	0	0	0	2,256
	Total	**29**	**96**	**56**	**725**	**718**	**1,909**	**6,882**
Hayward								
	Low	38	109	98	141	140	251	16,907
	Medium	0	1	0	1,203	1,200	2,950	91,257
	High	44	78	69	3,668	3,660	7,419	31,866
	Total	**82**	**187**	**167**	**5,011**	**4,999**	**10,620**	**140,030**
Oakland								
	Low	0	100	8	261	260	555	58,615
	Medium	6	646	176	1,777	1,765	3,233	67,946
	High	9	625	49	4,070	3,941	11,043	272,918
	Total	**16**	**1,370**	**233**	**6,107**	**5,965**	**14,831**	**399,484**
San Leandro								
	Low	222	560	265	1,344	1,302	1,677	4,240
	Medium	120	2,348	1,879	5,965	5,603	8,552	42,826
	High	14	1,338	1,077	2,761	2,541	5,236	32,386
	Total	**356**	**4,246**	**3,220**	**10,070**	**9,447**	**15,466**	**79,452**
San Lorenzo								
	Low	0	0	0	0	0	0	0
	Medium	13	200	177	2,888	2,628	5,337	18,602
	High	0	0	0	0	0	0	3,296
	Total	**13**	**200**	**177**	**2,888**	**2,628**	**5,337**	**21,898**
Union City								

	MHHW		100-year Stillwater		100-year + Wind and Waves		Population
	+ 16"	+ 55"	+ 16"	+ 55"	+ 16"	+ 55"	(for reference)
Low	6	1,723	516	1,905	1,905	2,941	10,913
Medium	348	9,742	1,632	14,469	14,701	22,014	38,747
High	0	6,475	2,700	8,879	8,894	9,208	17,209
Total	**353**	**17,940**	**4,849**	**25,253**	**25,501**	**34,163**	**66,869**
All Cities							
Low	402	6,364	3,591	12,780	12,808	19,803	112,548
Medium	1,472	19,803	8,104	39,730	39,516	59,871	293,109
High	78	12,100	5,625	27,554	27,309	44,111	381,212
Total	**1,952**	**38,266**	**17,320**	**80,065**	**79,633**	**123,786**	**786,874**
All Cities Percent of Total							
Low	21%	17%	21%	16%	16%	16%	14%
Medium	75%	52%	47%	50%	50%	48%	37%
High	4%	32%	32%	34%	34%	36%	48%

While SoVI scores provide a necessary indicator of overall social vulnerability within impacted areas, planning and preparation must also be informed by the presence of populations with singular vulnerabilities. Several social groups known to be more likely to experience adverse outcomes in flood events have significant populations in the study area. Under 16" and 55" 100-year storm event plus wind and wave scenarios, approximately 9,100 (33%) and 15,500 (36%) of the households at risk of inundation are occupied by renters, respectively, a population less likely to have the means to reinforce buildings and otherwise prepare for flood events (see Table 16).

Table 16 Renter-occupied households exposed to inundation risk

	MHHW		100-year Stillwater		100-year + Wind and Waves		Renter Households in City (for reference)	Total Households in City (for reference)
	+ 16"	+ 55"	+ 16"	+ 55"	+ 16"	+ 55"		
Alameda	82	2,235	1,319	5,139	5,210	7,245	15,740	30,226
Emeryville	12	39	23	285	283	740	2,499	3,975
Hayward	4	11	10	213	212	579	20,600	44,804
Oakland	3	265	73	1,128	1,106	3,744	88,301	150,790
San Leandro	9	369	290	732	686	1,153	12,078	30,642
San Lorenzo	1	10	9	121	110	229	1,558	7,500
Union City	4	1,142	357	1,497	1,505	1,845	5,278	18,642
Total	**115**	**4,071**	**2,081**	**9,115**	**9,112**	**15,535**	**146,054**	**286,579**

Table 17 Linguistically isolated households exposed to inundation risk

	MHHW		100-year Stillwater		100-year + Wind and Waves		Linguistically Isolated Households in City	Total Households in City
	+ 16”	+ 55”	+ 16”	+ 55”	+ 16”	+ 55”	(for reference)	(for reference)
Alameda	33	421	248	891	904	1,229	2,235	30,226
Emeryville	1	5	3	33	33	87	242	3,975
Hayward	2	4	4	137	137	281	5,000	44,804
Oakland	1	67	27	262	256	725	17,199	150,790
San Leandro	14	165	126	339	322	495	2,764	30,642
San Lorenzo	0	2	2	26	23	47	498	7,500
Union City	21	579	233	861	869	1,096	2,396	18,642
Total	**72**	**1,243**	**643**	**2,549**	**2,544**	**3,960**	**30,334**	**286,579**

Households without a member over age 14 who ‘speaks English well’ are considered by the US Census as “linguistically isolated” (See Table 17). Depending on the social networks available to these households, their lack of an English-speaking adult may prevent the members from having sufficient access to information about preparedness, response, and recovery. Households without a vehicle are at greater risk of harm during a sudden flood event. According to the 2000 Census, 3,800 households without a vehicle reside in the areas at risk of flooding under the most severe scenario considered in this study (Table 18).

Table 18 Households at risk of inundation with no vehicle

	MHHW		100-year Stillwater		100-year + Wind and Waves		Households with No Vehicle	Total Households
	+ 16”	+ 55”	+ 16”	+ 55”	+ 16”	+ 55”	(for reference)	(for reference)
Alameda	21	487	280	1,012	1,025	1,405	2,817	30,226
Emeryville	1	5	3	33	33	86	441	3,975
Hayward	2	5	4	86	86	191	3,449	44,804
Oakland	1	75	20	427	418	1,425	29,544	150,790
San Leandro	4	86	68	179	169	280	2,836	30,642
San Lorenzo	0	1	1	28	25	59	484	7,500
Union City	1	181	72	252	254	334	946	18,642
Total	**30**	**840**	**448**	**2,017**	**2,010**	**3,780**	**40,517**	**286,579**

Table 19 Low-income population at risk of inundation

	MHHW		100-year Stillwater		100-year + Wind and Waves		Low Income Population in City (for reference)	Population in City (for reference)
	+ 16"	+ 55"	+ 16"	+ 55"	+ 16"	+ 55"		
Alameda	128	2,197	1,218	5,172	5,246	7,340	14,285	72,259
Emeryville	7	22	13	168	167	443	1,814	6,882
Hayward	11	23	20	980	978	2,199	36,067	140,030
Oakland	6	612	97	3,267	3,188	7,474	159,634	399,484
San Leandro	32	625	483	1,352	1,268	2,055	14,485	79,452
San Lorenzo	1	17	15	339	308	631	3,525	21,898
Union City	20	3,098	851	4,243	4,266	5,102	11,270	66,869
Total	**205**	**6,594**	**2,697**	**15,521**	**15,421**	**25,244**	**241,080**	**786,874**

*Low income is defined in this study as people in households earning less than 200% of the national poverty level. In 2011, the threshold for a 4-person household is $22,350.

Low-income residents have fewer means to prepare for, respond to, and recover from flood events. Using a standard measure of poverty, we found that 15,600 to 25,000 people at risk of inundation are living off less than twice the federal poverty threshold, based on the 16-inch and 55-inch storm event plus wind and wave scenarios, respectively (Table 19). This comprises about 20 percent of the population exposed in both scenarios.

According to the Census, more than 300 people living in correctional and nursing and related institutions reside in areas at increased risk of flooding under the most severe scenario (Table 20). This population is almost entirely located in Alameda. The Census data does not reveal the specific type of institution housing the population.

Table 20 Institutionalized population at risk of inundation

	MHHW		100-year Stillwater		100-year + Wind and Waves		Institutionalized Population in City	Population in City
City	+ 16"	+ 55"	+ 16"	+ 55"	+ 16"	+ 55"	(for reference)	(for reference)
Alameda	0	73	40	225	230	294	469	72,259
Emeryville	0	0	0	0	0	0	0	6,882
Hayward	0	0	0	0	0	0	739	140,030
Oakland	0	1	0	5	5	18	2,894	399,484
San Leandro	0	0	0	0	0	0	517	79,452
San Lorenzo	0	0	0	0	0	0	0	21,898
Union City	0	0	0	0	0	0	212	66,869
Total	**0**	**74**	**40**	**230**	**235**	**312**	**4,831**	**786,874**

Table 21 People of color at risk of inundation

	MHHW		100-year Stillwater		100-year + Wind and Waves		People of Color	Population
City	+ 16"	+ 55"	+ 16"	+ 55"	+ 16"	+ 55"	(for reference)	(for reference)
Alameda	452	5,226	3,055	11,926	12,108	16,968	27,551	72,259
Emeryville	13	44	26	334	330	878	3,542	6,882
Hayward	35	78	70	2,561	2,555	5,735	72,007	140,030
Oakland	12	1,022	169	4,833	4,713	11,258	260,887	399,484
San Leandro	233	2,014	1,471	4,733	4,451	7,229	35,056	79,452
San Lorenzo	4	50	44	770	696	1,485	6,881	21,898
Union City	274	13,200	3,586	18,465	18,651	24,530	43,452	66,869
Total	1,023	21,634	8,421	43,622	43,504	68,083	449,376	786,874

Race has had significant influence on the effectiveness of past disaster preparedness and emergency response efforts. For instance, perceptions of emergency response workers toward neighborhoods that are predominantly people of color have increased the vulnerability of these communities (Klynman 2007). As shown in Table 21, in the cities in the study area there is a population of about 450,000 people of color (or non-white non-Hispanic population), comprising 57% of the cities' total population. Between 1,000 and 68,000 people of color are exposed to inundation under the various scenarios.

4 Exposure of Workplaces

More frequent flooding caused by sea level rise is likely to cause disruptions to key services, such as transportation, water, energy, and health care. Such disruptions are likely to cause an indirect economic impact, due to lost work days or increased travel times. In addition to the residences that may be exposed to flooding, a number of workplaces will also face increased flood risk. This includes coast-dependent workplaces such as ports and marinas (King et al. 2011), but also the many commercial and industrial buildings in low-lying areas adjacent to the Bay (Heberger et al. 2009). In this section, we describe the data and methods we used to estimate the exposure of workplaces to inundation in the ART study area.

4.1 Data

To estimate workplace exposure to inundation, we used employment information from FEMA's HAZUS database. The software contains a set of databases for each state; California's database can be found on the HAZUS data disc, in a file named CA1.mdb. Each state's database contains a table, "Occup," which includes data on the number of employees in each Census block. The data is aggregated according to the year-2000 census. HAZUS reports two classes of employee: Commercial and Industrial. The field names are WorkingCom and WorkingInd. The values in each field represent the number of employees in each Census Block. The information can be joined to the Census Block GIS file (feature class) via the field CensusBloc.

In the ART study area, the labor force was an estimated 291,000 employees in 2000 (Table 22). About 80% of employees in the ART study area are employed by the commercial sector, with 20% or about 58,000 in the industrial sector. Table 22 also shows households and population (also for year 2000) for reference.

Table 22 Number of employees by city in the ART study region in 2000 (number of households and population in 2000 shown for reference)

	Households	Population	Employees-Commercial	Employees - Industrial	Total Employees
Alameda	30,226	72,259	18,002	4,863	22,865
Emeryville	3,975	6,882	10,605	1,055	11,660
Hayward	44,804	140,030	48,127	18,585	66,712
Oakland	150,790	399,484	117,672	17,926	135,598
San Leandro	30,642	79,452	26,242	10,080	36,322
San Lorenzo	7,500	21,898	1,204	1,008	2,212
Union City	18,642	66,869	11,125	4,350	15,475
Total	286,579	786,874	232,977	57,867	290,844

4.2 Methods

To estimate the number of employees who would be exposed to flooding, we used the same methods that we used to estimate population exposure described in Section 3.2. We had previously determined the percentage of each Census block that is overlapped by the inundation hazard zones. We proceed as before, and use this information to estimate the percentage of workers in each Census block that is exposed to inundation risk. Thus, in a block with 1,000 workers that is 30% inundated, we assume that 300 workers are exposed to inundation risk. We used ArcGIS Spatial Analyst's Zonal Statistics as Table tool to determine the percentage of each Census block that is overlapped by the inundation hazard zone under each of the six scenarios. More details on the specific processing steps are included in Section 5.1.2.

4.3 Limitations

One source of inaccuracy has to do with uncertainties in the input data. Here, we are using the word "uncertainty" to mean that our data is not 100% accurate or up-to-date, not in the layperson's sense that our knowledge is murky. We used FEMA's HAZUS database because it is freely available, fairly well documented, and contains data for every Census block in the United States. We are not aware of similar datasets with such extensive coverage. (Data are available from the US Department of Labor's Bureau of Labor Statistics; however, these are aggregated at the state and county level and do not give the same level of geographic detail.)

HAZUS data represents the year 2000 and is already over a decade old. The employment numbers are estimates created for FEMA by Dunn & Bradstreet, a business listing company, using a proprietary algorithm. Thus, it is difficult to independently confirm the accuracy of the data. The HAZUS manual (FEMA 2006) also states that D&B aggregated some employment data at the census block group and tract level. Thus, the employment numbers may be distributed evenly over a large region, and may not accurately represent employment at a neighborhood scale.

The second source of inaccuracy stems from the analysis methods used. In short, we estimated the percentage of each Census block that is inundated under each flood scenario, and applied the same percentage to the employment. The area-weighted ration method is commonly used in GIS modeling, but has known limitations. For it to be reasonably accurate, one assumes that the variable of interest (in this case, number of employees) is homogeneous and uniformly spread over the surface of the block. When population occurs in clusters, and is not evenly distributed over an area, it means this method will be less accurate.

Finally, our results show only one measure of workplace exposure: the number of affected employees. There are a number of other methods of estimating direct and economic impacts of natural disasters that were beyond the scope of this study.

4.4 Results

Estimates of number of employees exposed to inundation are shown in Table 23. Note that these values represent employment estimates from year 2000. Table 24 reports the percentage of city's employees exposed to inundation, by scenario. Here, the percentage is calculated based on the total number of employees in each city (within the boundaries of the city, not just the portion in the ART study area). The employment data we used from the FEMA HAZUS model breaks down employees into two categories only: commercial and industrial. We report the numbers of employees exposed to inundation by sector in Table 25.

Table 23 Number of employees exposed to inundation, by flood scenario and by city

	MHHW		100-year Stillwater		100-year + Wind and Waves		Total Employees in City (for reference)
	+ 16”	+ 55”	+ 16”	+ 55”	+ 16”	+ 55”	
Alameda	3,310	7,193	6,002	13,446	12,099	15,686	22,865
Emeryville	29	50	36	512	2,436	5,055	11,660
Hayward	973	6,309	4,304	18,540	15,066	22,446	66,712
Oakland	921	11,676	4,584	32,134	29,642	49,229	135,598
San Leandro	110	2,403	1,857	5,030	6,572	9,517	36,322
San Lorenzo	34	605	450	1,328	1,241	1,380	2,212
Union City	198	1,697	1,076	5,979	4,975	6,556	15,475
Total	**5,574**	**29,933**	**18,308**	**76,969**	**72,033**	**109,868**	**290,844**

Table 24 Percentage of city's employees exposed to inundation, by scenario

	MHHW		100-year Stillwater		100-year + Wind and Waves	
	+ 16"	+ 55"	+ 16"	+ 55"	+ 16"	+ 55"
Alameda	14.5%	31.5%	26.2%	52.0%	52.9%	68.6%
Emeryville	0.3%	0.4%	0.3%	21.0%	20.9%	43.4%
Hayward	1.5%	9.5%	6.5%	22.7%	22.6%	33.6%
Oakland	0.7%	8.6%	3.4%	22.0%	21.9%	36.3%
San Leandro	0.3%	6.6%	5.1%	18.9%	18.1%	26.2%
San Lorenzo	1.5%	27.4%	20.3%	57.0%	56.1%	62.4%
Union City	1.3%	11.0%	7.0%	32.0%	32.2%	42.4%
Total	**1.9%**	**10.3%**	**6.3%**	**24.9%**	**24.8%**	**37.8%**

Table 25 Number of employees exposed to inundation, by sector

	MHHW		100-year Stillwater		100-year + Wind and Waves	
	+ 16"	+ 55"	+ 16"	+ 55"	+ 16"	+ 55"
Commercial	4,533	19,980	12,132	49,752	49,560	79,930
Industrial	1,041	9,953	6,176	22,583	22,472	29,938
Total	**5,574**	**29,933**	**18,308**	**72,335**	**72,033**	**109,868**

5 Value of Property Exposed to Flood Risk

We obtained estimates of property values from two sources. First, the Alameda County Assessor's Office provided assessed tax value for parcels, or individual units of land ownership. Second, FEMA's HAZUS model contains a database of replacement value of buildings and contents compiled at the Census Block level. Thus, we analyzed the value of property that may be exposed to future flooding using two different sources of information. In the following sections, we describe each of these analyses, including the data, methods, results, and limitations. At the end of this section, we compare the results obtained using the separate analysis methods, and give thoughts on how to make estimates of property value exposed to climate risks more robust.

5.1 Census Block Analysis with FEMA's HAZUS model database

5.1.1 Data

We used information in FEMA's HAZUS database to estimate the exposure of the built environment to future inundation due to sea level rise. Data on the value of buildings and contents was taken from datasets supplied with the HAZUS model, which was developed for FEMA's Mitigation Division by the National Institute of Building Sciences. HAZUS was designed to help planners estimate the potential losses from natural disasters such as earthquakes, floods, and hurricane winds. HAZUS uses a database called the "General Building Stock Inventory" that contains the value of buildings and contents based on data from a number of sources including the U.S. Census Bureau, Dun & Bradstreet (a business listing service), and the Department of Energy. Values are provided for residential, commercial, industrial, agricultural, religious, governmental, and educational developments in each census block. A detailed description of how this information was compiled is presented in the HAZUS Flood Technical Manual, Chapter 14 (FEMA 2006).

It is important to note that this study evaluates the replacement value of property at risk, not the expected flood damage. In many instances, flooding may not cause complete loss of a property, as the extent of damage depends on the type and quality of construction and depth of flooding. Concrete and steel structures, for example, may be habitable after being inundated while a more typical wooden residential structure may have sodden and rotting drywall and rotting beams. Thus we have purposely reported "assets at risk to flood damage" rather than "expected flood damage."

We follow the HAZUS methods for estimating direct economic losses, based on the repair and replacement of damaged or destroyed buildings and their contents. The HAZUS documentation includes the following under direct losses:

- Cost of repair and replacement of damaged and destroyed buildings
- Cost of damage to building contents
- Losses of building inventory (contents related to business activities)

HAZUS uses a statistical model to estimate rebuilding costs based on square footage, number of stories, building material, and other variables. As we discuss in Section 5.1.3, these values are likely to be significantly lower than market value for most properties. Table 26 shows the total replacement value of buildings and contents in each of the seven cities in the ART study area. This table reports totals for the entire city, not just flood-prone areas; note that values are reported in millions of dollars. The total is $45 billion across the seven cities.

Table 26 Replacement value of buildings and contents (from HAZUS) by sector in the ART study area (in millions of year-2000 dollars).

	Agric.	Religious	Residential	Commercial	Industrial	Govt.	Edu.	Total
Alameda	3.6	68.0	3,004.7	1,028.5	210.3	78.2	56.4	**4,450**
Emeryville	1.3	4.8	254.8	418.3	214.0	9.3	7.7	**910**
Hayward	11.4	107.6	4,262.9	2,268.3	1,295.7	35.9	128.5	**8,110**
Oakland	36.5	667.5	12,964.3	6,198.4	1,695.7	230.0	383.3	**22,176**
San Leandro	5.0	70.6	2,972.6	1,330.9	793.7	14.8	30.4	**5,218**
San Lorenzo	1.2	13.4	857.1	111.4	15.6	0.0	5.2	**1,004**
Union City	9.0	32.4	2,221.5	505.8	460.6	6.2	23.3	**3,259**
Total	**67.9**	**964.3**	**26,537.9**	**11,861.6**	**4,685.5**	**374.4**	**634.8**	**45,126**

5.1.2 Methods

We estimated the portion of the building stock value that is exposed to inundation risk using an area-weighted ratio overlay method, described in detail in Appendix D. The methods are analogous to those used to estimate the population at risk described above in Section 3.2, and are carried out at the Census block level. In brief, if a block contains $100,000 worth of buildings and is 30% inundated, we estimate that $30,000 worth of buildings is at risk. We repeated the analysis for each of the six inundation scenarios, and summarized the results for each of the 7 ART communities. We rounded all results to two significant digits to reflect the approximate nature of the analysis methods.

5.1.3 Limitations

In this section, we described how we estimated the value of property at risk of inundation under six sea level rise scenarios. There are several sources of uncertainty associated with this analysis. First, there are inaccuracies associated with the input data. We have shown previously that HAZUS data underestimates the market value of buildings and their contents (Heberger et al. 2009). We investigated replacement costs for residential buildings at a few locations and found that the replacement costs in HAZUS far underestimate actual market values for residential properties. We estimated that replacement value likely underestimates actual market values by a factor of four or more. In other words, actual losses of property value are likely four times higher than estimates based on replacement cost alone.

Second, some uncertainties are introduced due to the analysis methods. Information about building value is compiled at the Census block level, and we use the assumption common to many GIS analyses that the value is evenly distributed over the area of each block.

Third, our analysis summarizes the value of buildings that are exposed to inundation, but we have not attempted to estimate how the various flooding scenarios could inflict damage to different buildings. It is very difficult to predict whether flood exposure will be damaging. Flood depends on such factors as water depth and velocity, the duration of flooding, and the elevation of the building, along with its materials and quality of construction and maintenance, and the presence of any flood-proofing or other mitigation.

5.1.4 Findings

Below, we present results for the value of property in the inundation hazard zone analyzed using data from FEMA's HAZUS model. Table 27 shows the total replacement cost of buildings and contents exposed to flooding for each of the six scenarios, by city. The total building value in the city is included in the right column for reference. Table 28 reports the value of buildings in the inundation zones as a percent of each city's total building value. Under the highest scenario, more than $10 billion dollars' worth of assets are exposed to flooding. This represents 16% of the total asset value across the 7 cities. The results are even more striking in certain cities, for example Alameda, where nearly 66% of building value is exposed to flooding, or Union City where nearly 50% is exposed.

Table 27 Replacement costs of buildings and contents exposed to inundation, by city and by scenario (millions of year-2000 dollars).

	MHHW		100-year Stillwater		100-year + Wind and Waves		City Total
	+ 16”	+ 55”	+ 16”	+ 55”	+ 16”	+ 55”	(for reference)
Alameda	91	1,017	645	2,142	2,170	2,922	4,450
Emeryville	4	11	6	113	112	316	910
Hayward	75	373	258	958	973	1,506	8,110
Oakland	104	678	256	1,933	1,922	2,975	22,176
San Leandro	22	316	227	780	737	1,140	5,218
San Lorenzo	2	27	22	167	155	282	1,004
Union City	26	716	220	1,143	1,155	1,580	3,259
Total	323	3,139	1,633	7,236	7,224	10,721	45,126

Table 28 Percentage of each city’s total building value exposed to potential inundation, by scenario; HAZUS analysis

	MHHW		100-year Stillwater		100-year + Wind and Waves	
	+ 16”	+ 55”	+ 16”	+ 55”	+ 16”	+ 55”
Alameda	2.0%	22.9%	14.5%	48.1%	48.8%	65.7%
Emeryville	0.4%	1.2%	0.6%	12.4%	12.3%	34.7%
Hayward	0.9%	4.6%	3.2%	11.8%	12.0%	18.6%
Oakland	0.5%	3.1%	1.2%	8.7%	8.7%	13.4%
San Leandro	0.4%	6.1%	4.4%	15.0%	14.1%	21.9%
San Lorenzo	0.2%	2.7%	2.1%	16.6%	15.4%	28.1%
Union City	0.8%	22.0%	6.7%	35.1%	35.5%	48.5%
Total	0.7%	7.0%	3.6%	16.0%	16.0%	23.8%

5.2 Analysis Based on Parcels and Assessor’s Data

In the previous section, we described our analysis of property (buildings and contents) that are exposed to inundation using data from FEMA’s HAZUS model that is compiled at the Census block level. In this section, we describe a similar analysis done with a different dataset. Here, we repeat this analysis with the smaller geographic unit of Parcel boundaries.

Parcels are the basic units of land ownership, and are defined by a plat diagram of its boundaries. Historically, parcel maps (also referred to as a cadastral survey or landbase) have been maintained by local governments to regulate land ownership and as a basis for levying taxes. Today, many counties in California maintain digital databases in GIS format. Our analysis was greatly facilitated by the fact that Alameda County offers free downloads of GIS data, and releases the tax roll data for a nominal fee.

5.2.1 Data

Data from Alameda County Assessor’s Office included (a) a GIS file of parcel boundaries, and (b) the property database, a table containing information about land and properties. The county maintains this information for the purpose of levying taxes. Each parcel in the county has a unique identifier, the Assessor's Parcel Number, or APN. The corresponding database is a flat file, or a single table, containing information about each parcel in the county, identified by its APN. The Assessor's office continually updates this database, and publishes new versions periodically. The GIS file of parcel boundaries is a shapefile that we downloaded from the county website (Alameda County 2011). The shapefile's coordinate system (NAD 1983 State Plane California III FIPS 0403 Feet) was not the same as the standard chosen for this project. We re-projected the data to NAD 1983 California Teale Albers as described in section 2.2.2. During the same processing step, we loaded this data as a feature class in an ESRI Personal Geodatabase (.mdb) file.

We purchased the property database (Alameda County 2012) in person at the county offices in Oakland. The data table was in text format. We loaded this data into a table in Microsoft Access, taking care to preserve the proper format (text vs. numeric) for each field.

To estimate property values based on the Assessor's Database, we added all fields related to property value, and *did not* include tax exemptions. We created new columns, or fields, in the data table and set their values through a series of update queries in MS Access. (We wrote queries using a combination of the Access Query Design View and by editing SQL manually. These queries are available on request from the authors.) The new fields included:

- Land
- Improvements (buildings and structures)
- Personal property
- Household personal property

We also created a field for the value of buildings and contents (including improvements and personal property, but not land). We did this for two reasons. First, it is a different measure of possible flood damages that may be of interest. A flood event may damage buildings and property, but may not have an effect on the underlying value land, unless for example the land is badly eroded, or a regulatory agency prohibits rebuilding in flood-damaged areas. Second, this allowed us to compare the results of the parcel-based analysis with the analysis done using the HAZUS model, which estimates the value of flood-affected buildings and contents only, and does not include the value of land.

The assessor's table contained dozens of use categories. These were grouped and simplified into the 23 categories shown here by BCDC staff. This cross-reference from the Alameda County Assessor's Office land use classifications to custom BCDC land use category is shown in Table 41 in Appendix B.

Table 29 summarizes the Assessor's data that we used as the input data in our analysis. Assessed value is reported in millions of dollars. Values are current as of January 1, 2012. The total assessed value of land, buildings, and property in the 7-city ART study area is 86.6 billion dollars. In Table 30, we report the number of parcels and assessed value by city.

Table 29 Assessed value of land and improvements in the 7 cities in the ART study area, by land use type (total within city boundaries; value in millions of dollars, as of Jan 2012)

Land Use	Number of Parcels	Value of Land	Value of Improvements and Property	Total Value
Agriculture	64	17.3	3.3	20.7
Care Facility	192	89.4	370.4	459.8
Cemetery	48	20.3	44.9	65.2
Commercial	7,573	3,394.0	7,829.9	11,223.9
Condominium	24,919	1,456.4	3,408.5	4,864.9
Floating Home	41	0.0	7.5	7.5
Golf Course	33	13.7	20.9	34.7
Grocery	47	54.4	82.3	136.7
Historic Residential	24	1.4	3.2	4.6
Hospital	69	75.8	1,029.2	1,105.0
Hotel	55	72.4	229.7	302.1
Industrial	3,895	2,601.0	5,853.2	8,454.2
Mixed Use	1,508	253.1	636.2	889.3
Mobile Home	1,156	126.0	82.8	208.7
Motel	101	72.3	179.9	252.2
Multi-Family Residential	31,436	4,057.6	9,240.8	13,298.4
Public	6,807	12.3	21.6	33.9
Recreation	32	19.9	22.7	42.7
Residential	203	25.6	55.0	80.5
Rural	61	19.1	6.9	26.0
Salt Ponds	10	1.9	0.0	1.9
School	200	93.7	462.9	556.6
Single Family Residential	152,612	13,861.2	29,198.4	43,059.6
Vacant Commercial	761	231.9	68.9	300.8
Vacant Industrial	772	215.2	28.4	243.6
Vacant Residential	4,674	328.8	47.3	376.1
Vacant Rural	4	0.0	0.0	0.0
Unknown	1,709	168.7	373.1	541.8
Total	239,006	27,283.4	59,307.8	86,591.1

Table 30 Assessed value of land and improvements in the 7 cities in the ART study area, by city (in millions of dollars, as of Jan 1, 2012)

City	Number of Parcels	Value of Land	Value of Improvements and Property	Total Value
Alameda	20,576	2,987	5,889	8,877
Emeryville	5,151	904	2,608	3,512
Hayward	45,733	5,395	10,920	16,315
Oakland	111,230	11,670	26,501	38,171
San Leandro	28,342	3,292	6,598	9,890
San Lorenzo	9,308	759	1,505	2,264
Union City	18,666	2,277	5,285	7,563
Total	239,006	27,283	59,308	86,591

5.2.2 Methods

The analysis methods we used are similar to those used for the Census block-based analysis in the previous section, and described in detail in Appendix D. The main difference was that we used parcel boundaries as the polygon vector file instead of Census blocks. We used the ArcGIS Spatial Analyst tool "Zonal Statistics as Table" to calculate the percentage of each parcel that is inundated by floodwaters. Figure 4 shows an example of how flood percentage was calculated for each parcel.

After calculating the Zonal Statistics, some of the parcels contained "Null" values for flood percentage. This resulted from parcels whose geometry does not overlap the inundation raster. In reality, these are parcels that are far from the shoreline and are not covered by the floodplain rasters. We used ArcMap's Field Calculator to convert Null values to 0 in these fields.

At this point, our analysis method diverged. For the census blocks, we used an area-weighted ratio method to determine the *fraction* of each block's building value that is exposed to inundation. Parcels represent smaller geographic areas. For parcels, we simply determined whether it is exposed to inundation, using a true/false condition.

We created a set of 6 Boolean (true/false) fields in the Parcel attribute table. These new fields indicate whether each parcel was flooded or not. We named these fields as follows:

- b_mhhw16
- b_mhhw55
- b_sw16
- b_sw55
- b_ww16
- b_ww55

In practice, ArcGIS does not allow the creation of a Boolean field in attribute tables, so we created an Integer field, and used 1 to represent flooded, and 0 to represent not flooded. The rule was: if the fraction flooded is greater than 0, then the block is considered flooded. While this rule means that some parcels where only 1% is flooded end up flagged, we felt that this was appropriate. The boundary of the inundation hazard zone is inexact; if the parcel is near that boundary, it is possible that the property is exposed to some flooding.

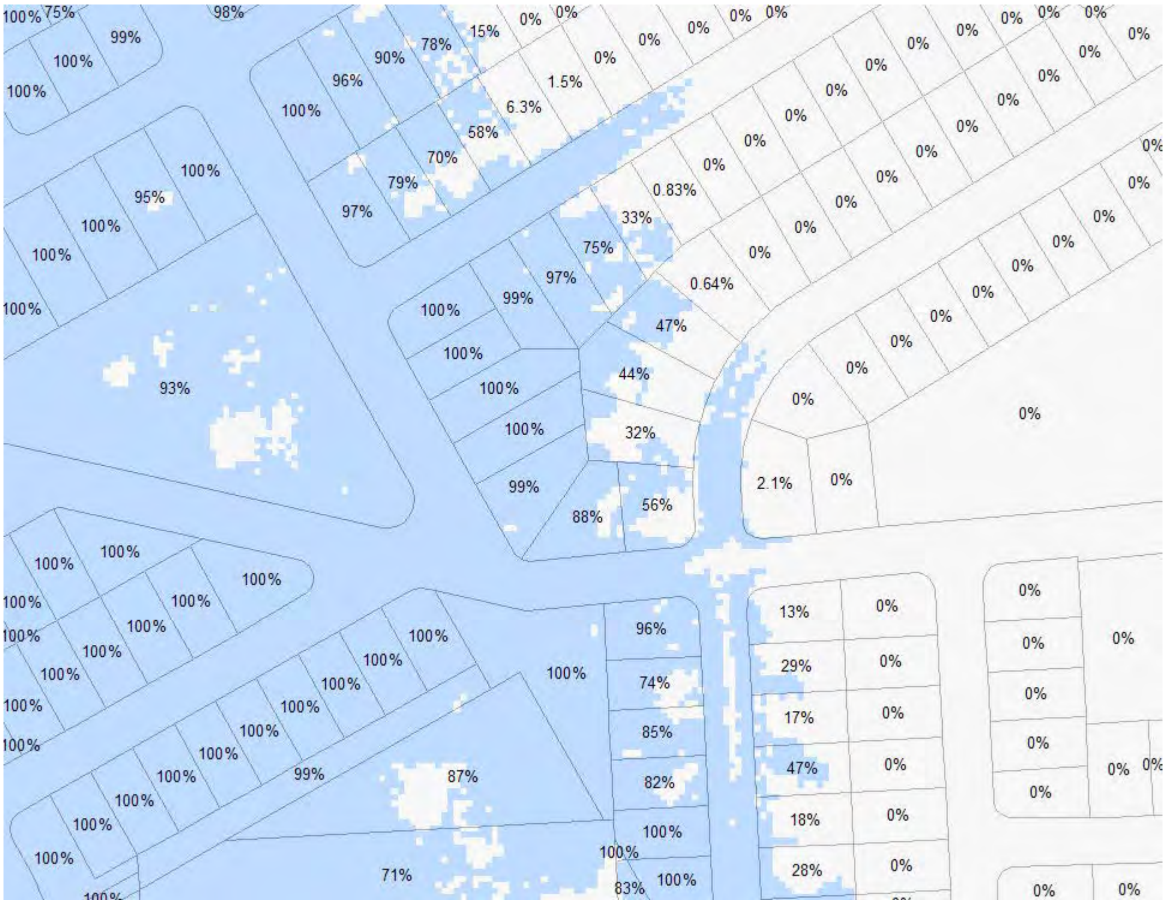


Figure 4 Example of overlay of the flood raster layer (blue shading) with the parcel boundary polygons to determine percent of each parcel in the study area that is exposed to flooding

5.2.3 Limitations

The data presented challenges for conducting analyses for this study. The assessor's database does not include any publicly-owned buildings, so it excludes many police and fire stations, government buildings, park buildings, schools, water treatment plants, etc.

It is likely that assessed values in the database are below the actual market values for many properties in California. Properties are assessed continuously, for example when a home is built or sold, thus the assessments do not all share a base year. California's Proposition 13 (1978), lowered property taxes by assessing property values at a base year of 1975, and prohibited local government from raising the assessed value by more than 2% per year. Proposition 8, passed in the same year, allowed counties to re-assess properties in a declining market. Since the passage of these laws, it has been written into the California Constitution (Amendment 13), that assessed property values should be lower than market value. In a recent study for the California Department of Boating and Waterways, King et al. (2010, p. 27-28) describe other reasons why assessor's data do not always reflect market value. They concluded that the assessor's office estimation of property values does not seem to realistically reflect the market value of personal property and household property, especially at residences. We confirmed this by analyzing the Alameda County Assessor's Office database. In the fields "Personal Property" and "Household Personal Property," over 90% of the records contain a value of 0. Land use categories hospitals, schools, and industrial, are more likely to contain a non-zero value. However, for "single-family residential," the average value of personal property is $8, and average household personal property is $0. Surely, the average resident of Alameda County owns possessions worth more than $8; thus common sense indicates that the county's assessments are unrealistically low.

On close examination, the property values in the Assessor's database seem unrealistically low, especially for single-family residences. Of the 8,951 single-family residential parcels in Oakland, only 20 are assessed at more than $400,000. The highest value for a single-family residential parcel in Oakland is $750,000, for a 1,463 square foot home in the Golden Gate neighborhood of northwest Oakland. The majority of single-family homes are assessed at under $200,000. However, one can easily find dozens of homes in Oakland on sale for over a million dollars by looking at the real estate listings of the local paper or online at zillow.com. This strengthens our conclusion that using Assessor's Office data to estimate property values results in significant underestimates compared with market value.

Finally, the "total net taxable value" may include one or more deductions. In Alameda County, homeowners are eligible for a "homeowner's exemption" of $7,000 if the property is his or her primary residence. Additional exemptions are granted to nonprofits such as schools, hospitals, churches, and other public-benefit organizations. The total exemptions may exceed the value of the property, resulting in a net taxable value of $0.

5.2.4 Findings

The results of the parcel-based analysis are reported below. Table 31 shows the number of parcels subject to inundation city and by flood scenario. Table 32 reports the assessed value of parcels exposed to inundation risk, by city and by scenario. Table 33 reports the percentage of the property value in each city that is exposed to inundation under each scenario.

Table 31 Number of parcels exposed to inundation risk, by city and by scenario

	MHHW		100-yr Stillwater		100-yr + Wind + Waves		Total # Parcels in City
	+ 16"	+ 55"	+ 16"	+ 55"	+ 16"	+ 55"	(for reference)
Alameda	631	5,694	3,600	9,262	9,318	11,857	20,576
Emeryville	9	31	20	141	137	227	5,151
Hayward	121	1,147	769	2,629	2,638	4,223	45,733
Oakland	118	1,415	302	3,255	3,217	5,234	111,230
San Leandro	72	1,467	889	3,736	3,600	5,039	28,342
San Lorenzo	11	79	62	1,319	1,222	2,151	9,308
Union City	26	5,378	1,642	6,824	6,933	9,044	18,666
Total	988	15,211	7,284	27,166	27,065	37,775	239,006

Table 32 Value of parcels potentially exposed to inundation, by city and by scenario (in millions of dollars, assessed value as of January 1, 2012)

	MHHW		100-yr Stillwater		100-yr Wind + Waves		Total Assessed Value in City
	+ 16"	+ 55"	+ 16"	+ 55"	+ 16"	+ 55"	(for reference)
Alameda	370	2,665	1,807	4,589	4,623	5,800	8,877
Emeryville	86	112	89	726	704	1,271	3,512
Hayward	48	1,203	743	2,466	2,470	3,214	16,315
Oakland	182	1,158	375	2,396	2,403	3,017	38,171
San Leandro	8	802	464	1,607	1,561	2,022	9,890
San Lorenzo	1	76	49	373	353	551	2,264
Union City	0	1,859	589	2,964	3,017	3,730	7,563
Total	694	7,875	4,117	15,122	15,132	19,605	86,591

Table 33 Value of parcels potentially exposed to inundation, as percentage of the value of each city's parcels

	MHHW		100-yr Stillwater		100-yr Wind + Waves	
	+ 16"	+ 55"	+ 16"	+ 55"	+ 16"	+ 55"
Alameda	4%	30%	20%	52%	52%	65%
Emeryville	2%	3%	3%	21%	20%	36%
Hayward	0%	7%	5%	15%	15%	20%
Oakland	0%	3%	1%	6%	6%	8%
San Leandro	0%	8%	5%	16%	16%	20%
San Lorenzo	0%	3%	2%	16%	16%	24%
Union City	0%	25%	8%	39%	40%	49%
Total	**1%**	**9%**	**5%**	**17%**	**17%**	**23%**

Table 34 reports the assessed value of land and improvements (including buildings) for flooded parcels, by land use classification.

Table 34 Assessed value of parcels potentially exposed to inundation under scenarios of future sea level rise, by land use classification (in millions of dollars, assessed value as of January 1, 2012).

	MHHW		100-yr Stillwater		100-yr Wind + Waves		Total
	+ 16"	+ 55"	+ 16"	+ 55"	+ 16"	+ 55"	(for reference)
Agriculture	-	1.87	1.87	1.87	1.87	1.87	20.67
Care Facility	10.31	54.91	42.70	58.75	58.75	106.52	459.77
Cemetery	-	-	-	-	-	-	65.21
Commercial	235.20	1,007.02	591.89	2,161.65	2,148.24	2,837.48	11,223.88
Condominium	0.35	0.69	0.38	12.84	13.44	16.00	4,864.86
Floating House	-	-	-	-	-	-	7.48
Golf Course	-	-	-	-	-	-	34.66
Grocery	-	0.09	-	0.09	0.09	16.63	136.71
Historic Residential	-	-	-	-	-	0.24	4.64
Hospital	-	4.81	-	6.56	6.56	6.56	1,105.00
Hotel	-	22.88	8.46	162.41	162.41	165.89	302.12
Industrial	127.46	1,939.04	1,045.13	4,096.34	4,063.17	5,019.93	8,454.16
Mixed Use	0.30	5.40	4.52	23.06	23.06	37.36	889.29
Mobile Home	40.52	46.05	46.05	72.79	72.75	72.79	208.75
Motel	5.49	67.62	32.13	141.56	141.56	154.72	252.16
Multi-Family Residential	95.85	876.21	449.55	1,482.46	1,499.38	1,849.36	13,298.37
Public	0.00	0.01	0.00	2.49	2.49	2.59	33.85
Recreation	17.82	27.59	27.59	27.59	27.59	27.65	42.66
Residential	-	22.03	2.09	36.08	36.08	38.72	80.51
Rural	0.00	0.07	0.00	0.07	0.07	0.07	26.00
Salt Ponds	0.27	0.88	0.88	0.88	0.88	0.88	1.86
School	-	3.43	2.99	28.31	31.51	41.88	556.58
Single Family Residential	130.88	3,630.13	1,792.75	6,560.51	6,596.16	8,925.85	43,059.63
Vacant Commercial	26.45	78.79	35.32	113.24	113.24	118.32	300.81
Vacant Industrial	2.57	66.62	29.38	107.76	107.54	133.41	243.60
Vacant Residential	0.61	18.46	3.47	24.87	24.89	29.90	376.10
Vacant Rural	-	-	-	-	-	-	-
Unknown	-	-	-	-	-	-	541.79
Total	694.09	7,874.58	4,117.14	15,122.16	15,131.71	19,604.61	86,591.11

*Total for all parcels within the boundaries of the 7 cities in the ART study area

5.3 Comparison of Results

In this section, we analyze the results of our analysis of property value exposed to inundation using two different sources of information, as described above in Sections 5.1 and 5.2.

The replacement value of buildings and contents derived from FEMA's HAZUS Database is 31% less than the assessed value of improvements, and property from the Alameda County Assessor's Office (Table 35). (The values in Table 35 summarize the value of buildings and contents within the boundaries of each of the 7 study-area cities, not just the portion in the study area near the shoreline.). We believe that HAZUS tends to smooth values out, causing it to assign relatively lower values to property near the waterfront. The parcel database may contain a more accurate representation of high-value commercial and industrial buildings, which tend to be clustered near the waterfront.

Table 35 Comparison of the total value of buildings and contents in ART study cities from two data sources: FEMA's HAZUS model database and Alameda County Office of the Assessor (in millions of dollars)

	Replacement value of buildings and contents from FEMA's HAZUS Database (in millions of year-2000 dollars)	Assessed value of Property and Improvements (excludes Land) from the Alameda County Assessor's Office, Jan 1, 2012	Percent Difference
Alameda	4,449	5,889	+32%
Emeryville	910	2,608	+187%
Hayward	8,110	10,920	+35%
Oakland	22,176	26,501	+20%
San Leandro	5,218	6,598	+26%
San Lorenzo	1,004	1,505	+50%
Union City	3,259	5,285	+62%
Total	45,126	59,308	+31%

Further, a previous Pacific Institute study (Heberger 2009) concluded that FEMA's estimates of replacement value were significantly lower than actual market value. This indicates limitations to using public datasets to accurately estimate property values. All of the results reported here are likely much lower than the actual *market value* for properties. The HAZUS database reports the estimated cost to rebuild structures and to replace their contents. The Assessor's Office database is assembled for the purpose of levying taxes; it is not intended to accurately reflect market value. In a recent study, economists from San Francisco State noted that Assessor's "values are prone to underestimating the market value of land and should therefore be considered conservative" (King et al. 2011).

Based on the limitations in each of these datasets, we conclude that each is likely to underestimate property values. As these were the most readily-available public datasets, we proceeded with the analysis. However, this limitation should be kept in mind when interpreting the results.

6 Community Assets and Liabilities Exposed to Flood Risk

We use the term "community assets and liabilities" to describe a class of geographic features that can be represented as *points* on a map and in a GIS database. In order to assess community vulnerability and adaptation needs, we looked at a wide a range of features that represent locations and facilities that may be exposed to flood risk in the future. In this section, we describe the data and methods we used to determine which of these facilities may be exposed to inundation under each sea level rise scenario.

6.1 Data

We created a GIS database of community assets and liabilities as a Point Feature Class in an ESRI Personal Geodatabase (PGDB). *Community Assets* represent features that are important to the welfare of the community. In particular, we focused on locations which are home to or serve vulnerable populations. Examples include Child Care Facilities, Food Banks, Homeless Shelters, Schools, and Senior Housing. *Community Liabilities* include facilities where toxic waste or other dangerous substances are present, and which may be released or mobilized during a flood or other natural disaster.

Table 36 shows a full listing of the classes of community assets that we researched and included into our database. We were limited by the availability of publicly-available data. In a few cases, we developed new data layers by researching the location of certain features via internet searches and phone calls. We divided the 20 different types of features into 5 major types:

- Community Assets and Vulnerable Populations
- Contaminated Sites
- Critical Facilities
- Emergency Response
- Health care

Table 36 Data sources for community assets and liabilities

Data Set	Source
Community Assets & Facilities with Vulnerable Populations	
Child Care Facilities	California Community Care Licensing Division
Food Banks	California Community Care Licensing Division
Group Homes	California Community Care Licensing Division
Homeless Shelters	California Community Care Licensing Division
Schools	FEMA HAZUS
Senior Housing	California Community Care Licensing Division
Jails	Internet research; manually entered addresses
Contaminated Sites	
Cleanup Program Sites	BCDC
DTSC-listed sites	BCDC
Leaking Underground Storage Tanks	BCDC
Military Sites	BCDC
RCRA-listed sites	EPA Envirofacts (via BCDC)
Landfills and Waste Facilities	BCDC
Critical Facilities	
Critical Facilities – City and County	Association of Bay Area Governments (ABAG)
Critical Facilities – Special District	Association of Bay Area Governments (ABAG)
Emergency Response	
Fire Stations	FEMA HAZUS
Police Stations	FEMA HAZUS
Health Care	
Hospitals	FEMA HAZUS
Health Care Facilities	CA Dept. of Public Health
Long-Term Care Facilities	CA Dept. of Public Health

Critical facilities were identified by the Association of Bay Area Governments (ABAG 2010). ABAG identifies these as “several types of facilities are critical to the functioning of our region after disasters and during the recovery process.” The types of data included in their database are:

- Health-related facilities (based on a list of licensed facilities from the California Office of Statewide Health Planning and Development)
- Schools (location information on public and private K-12 schools, community colleges, colleges, and universities based on a combination of addresses from Thomas Bros. and the individual facilities)
- Critical facilities (owned by cities, counties, and special districts other than K-12 school districts)
- Highway and road structures, including freeway interchanges, small bridges over creeks, and toll bridges (location information based on data from Caltrans)

Contaminated sites include sites that are listed by the California Department of Toxic Substances Control (DTSC) and by the US EPA under the Resource Conservation and Recovery Act (RCRA). RCRA is a federal law that was passed in 1976 that requires all Treatment, storage, and disposal facilities (TSDFs) that manage hazardous wastes to have a permit in order to operate. Other contaminated sites include leaking underground storage tanks, landfills, and active cleanup sites.

We merged the 20 individual GIS data files to create a single "asset database" containing 2,656 points. The locations of the facilities in our community assets database are shown in Figure 5. Table 37 lists the number of facilities in our database, by city and by type. It should be noted that our database is not complete; it does not necessarily cover all of the area inside the boundaries of each of the 7 study communities. This is due to two reasons. First, the data that we received from BCDC was clipped to the study area, and did not include the eastern portions of Hayward and Union City. Second, with the data sets that we developed via independent research, we focused our efforts on the area in and near the inundation hazard zone. This should be kept in mind when interpreting the results in this section.

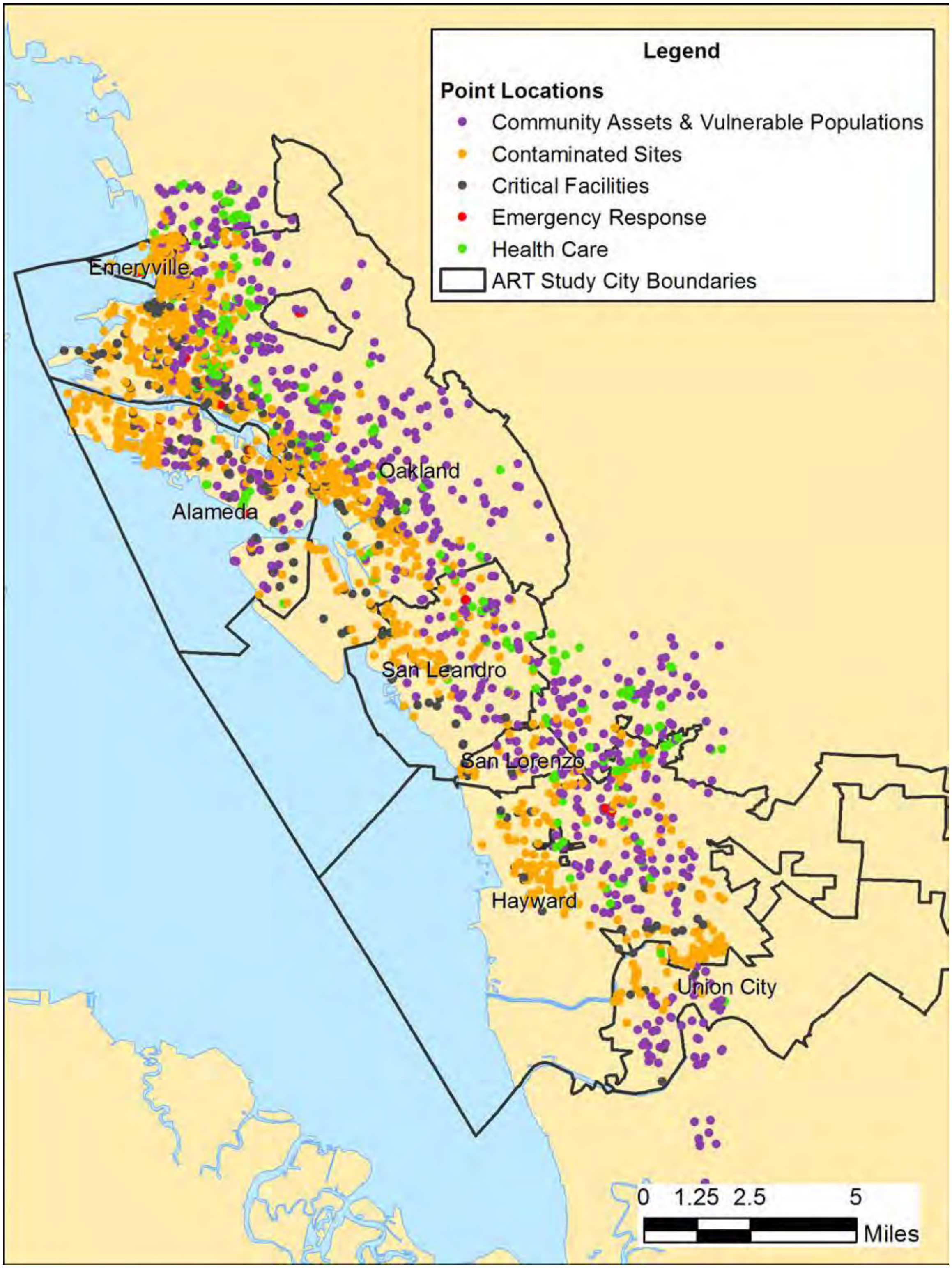


Figure 5 The locations of the community assets and liabilities in the ART study area, shown by major type.

Table 37 Number of Community Assets and Liabilities in project database, by city and by type.

	Alameda	Emeryville	Hayward	Oakland	San Leandro	San Lorenzo	Union City	Total
Community Assets & Vulnerable Populations								
Child Care Facilities	31	4	35	149	26	11	5	261
Food Banks	2	0	7	15	4	2	1	31
Group Homes	0	0	4	19	2	0	1	26
Homeless Shelters	0	0	2	12	0	0	0	14
Jails	1	0	1	1	1	0	0	4
Schools	29	4	43	83	25	14	7	205
Senior Housing	12	1	46	47	24	9	25	164
Contaminated Sites								
Cleanup Program Sites	19	42	41	151	30	3	5	291
DTSC-listed sites	7	18	10	66	6	0	1	108
Leaking Undg. Storage Tanks	32	37	66	201	24	15	15	390
Military Sites	124	0	5	10	0	0	0	139
RCRA-listed sites	15	46	69	77	23	1	7	238
Landfills and Waste Facilities	4	2	2	9	4	0	1	22
Critical Facilities								
City and County	48	6	18	47	5	0	4	128
Special District	15	6	15	138	15	0	3	192
Emergency Response								
Fire Stations	2	1	0	5	0	0	0	8
Police Stations	3	1	2	6	1	0	0	13
Health Care								
Health Care Facilities	9	4	38	120	26	2	3	202
Hospitals	1	0	2	4	3	0	0	10
Long-Term Care Facilities	7	0	16	21	8	0	0	52
Total	**361**	**172**	**422**	**1181**	**227**	**57**	**78**	**2,498**

6.2 Methods

Because of the large file sizes of the inundation hazard zone rasters datasets, we initially encountered some difficulty in performing an overlay analysis with the point layers. To complete the analysis, we used the procedure described below, which worked reliably, and which we verified to be accurate. The first steps were to verify the accuracy of the point locations and to make some adjustments to improve their accuracy.

6.2.1 Correcting Point Locations

In reviewing a subset of the 2,656 points in the asset database, we found that most points were slightly inaccurate, while some were up to ¼ mile from their true location. We manually edited a few dozen points with obvious errors and updated the location of many points that had a street address by using the Google Maps Geocoding API. We did this by using a short script written in Python (see Appendix E).

We had some concern that automatically querying Google's service may be a violation of their terms of service, so we contacted a Google Maps administrator who gave us permission to proceed (Christian Adams, personal communication, January 11, 2012). Google's algorithms locate most points at parcel centroids, rather than clamped to a road. While we found this to improve the locations considerably, we did not attempt to verify the precise location for all 2,656 points. Geocoding routines seem to be the least accurate for buildings on large lots, such as high schools and water plants.

We also made several corrections to the attribute table. Some records included incorrect entries, for example listing the name of the city as "Haywood" rather than "Hayward." Other records incorrectly used neighborhood names, such as "Alameda Point," rather than the city name "Alameda."

6.2.2 Adjusting Overlapping Points

Further, a number of the points were overlapping (i.e. they had identical coordinates) after geocoding. This was mostly a problem with the wastewater layers. We found that overlapping points and polygons caused some of ESRI's Spatial Analyst tools to fail.

Several of the datasets we received from public agencies contained overlapping points, which had to be adjusted slightly in order to perform our analysis. This appears to be the result of multiple records with the same address. For example, the Critical Facilities database we received from the Association of Bay Area Governments (ABAG) contains several entries at the East Bay Municipal Utility District's wastewater treatment plant, as shown in Figure 6. There were four facilities represented by overlapping points with identical coordinates: the Administration Building, Fuel Location, Warehouse, and Field Services.

When we attempted to perform an overlay analysis in ArcGIS to determine which locations overlap the inundation hazard zone, the program produced an error and stopped unexpectedly. A little research revealed that this issue occurs with overlapping features with coincident geometries. The same issue occurs regardless of geometry type (e.g. for points, polylines, and polygons.). In order to proceed, we "nudged" the points by a small distance (about 5 feet). Thus, the points remain in essentially the same location, and the geoprocessing tools can run without errors.

Figure 6 Example of multiple points occurring in a cluster at the EBMUD wastewater plant.

Note that ArcGIS has a built-in "Disperse Markers" tool that performs a similar function. However, this tool only adjusts the drawing layer in ArcMap, and not the underlying data. In other words, the point coordinates are not adjusted, but the program displays a cluster of points rather than a single dot where multiple points overlap.

We wrote a pair of custom functions in Excel VBA to disperse overlapping markers. These functions, listed in Appendix B, move a set of overlapping points by a small distance so that they are no longer overlapping. It does this by creating a new, revised pair of latitude and longitude coordinates that are slightly offset from the original. An example of its application is shown in Table 38. In this example, there are 17 points with the identical latitude and longitude coordinates. The function leaves the first point it encounters in the original position. It takes the rest of the remaining points, and moves them outward in concentric rings, at a set distance from the original, as shown in Figure 7. After we made minor adjustments to overlapping points so that each point had its own unique coordinates (even though several were very close to one another), the geoprocessing tools operated as expected and produced good results.

Table 38 Example of the disperse markers code.

PointID	Latitude	Longitude	Latitude-Revised	Longitude-Revised
1	37.8255160	-129.2925440	37.82551600	-129.29254400
2	37.8255160	-129.2925440	37.82553721	-129.29252279
3	37.8255160	-129.2925440	37.82554600	-129.29254400
4	37.8255160	-129.2925440	37.82553721	-129.29256521
5	37.8255160	-129.2925440	37.82551600	-129.29257400
6	37.8255160	-129.2925440	37.82549479	-129.29256521
7	37.8255160	-129.2925440	37.82548600	-129.29254400
8	37.8255160	-129.2925440	37.82549479	-129.29252279
9	37.8255160	-129.2925440	37.82551600	-129.29251400
10	37.8255160	-129.2925440	37.82551600	-129.29248400
11	37.8255160	-129.2925440	37.82555842	-129.29250158
12	37.8255160	-129.2925440	37.82557600	-129.29254400
13	37.8255160	-129.2925440	37.82555842	-129.29258642
14	37.8255160	-129.2925440	37.82551600	-129.29260400
15	37.8255160	-129.2925440	37.82547358	-129.29258642
16	37.8255160	-129.2925440	37.82545600	-129.29254400
17	37.8255160	-129.2925440	37.82547358	-129.29250158

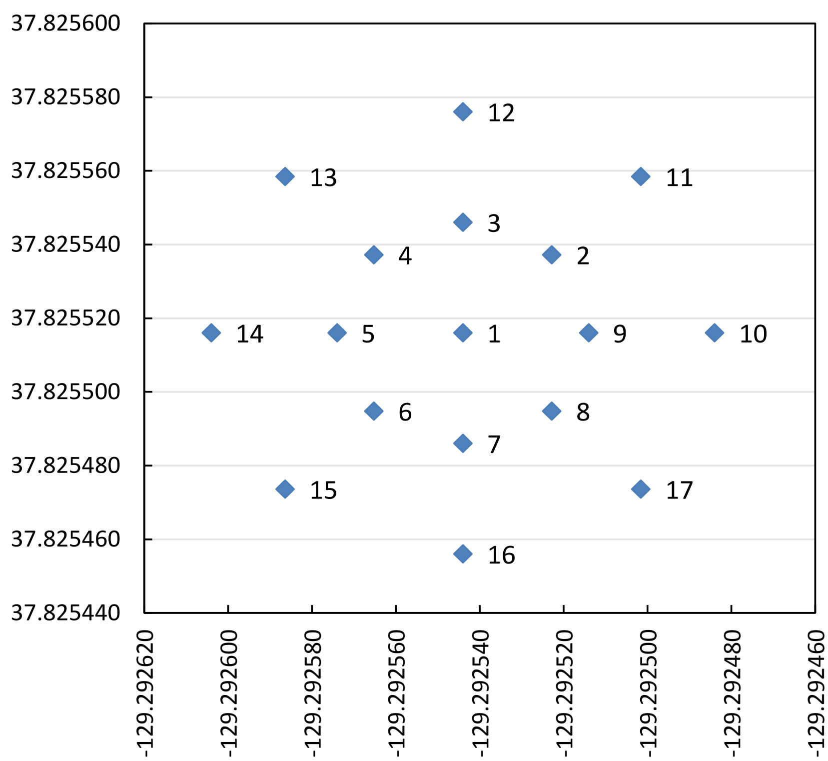


Figure 7 Demonstration of the disperse markers tool.

6.2.3 Converting Points to Polygons

First, we converted the point feature class to circular polygons with a 25 m radius using the Buffer tool. The circular polygon approach also helps compensate somewhat for the problem of inaccurate or arbitrary placement of point features to represent polygon features. We had previously experimented with the approach of overlaying the points with the inundation raster. This approach extracts a raster value to a point layer. Theoretically, this would result in exactly the information we were looking for: is the point inside or outside of the inundation hazard zone.

We found, however, that overlaying points with the inundation raster resulted in occasional false negatives and false positives. A false negative (structure is not in the inundation zone) is shown in Figure 8. In this example, the floodwaters cover over ¾ of the building, but the point representing the building lies just outside the inundation zone. A false positive is shown in Figure 9. Here, the actual building is outside of the inundation hazard zone. However, the point representing the building is inaccurate, and is not located directly above the building. Rather, it is located along the adjacent road. (This facility's address is on Edes Road, and the geocoding algorithm located the point along the polyline that represents Edes Road.) This is common with points that have been automatically geocoded by computer.

Figure 8 Example of a situation where a simple point-based analysis results in a false negative.

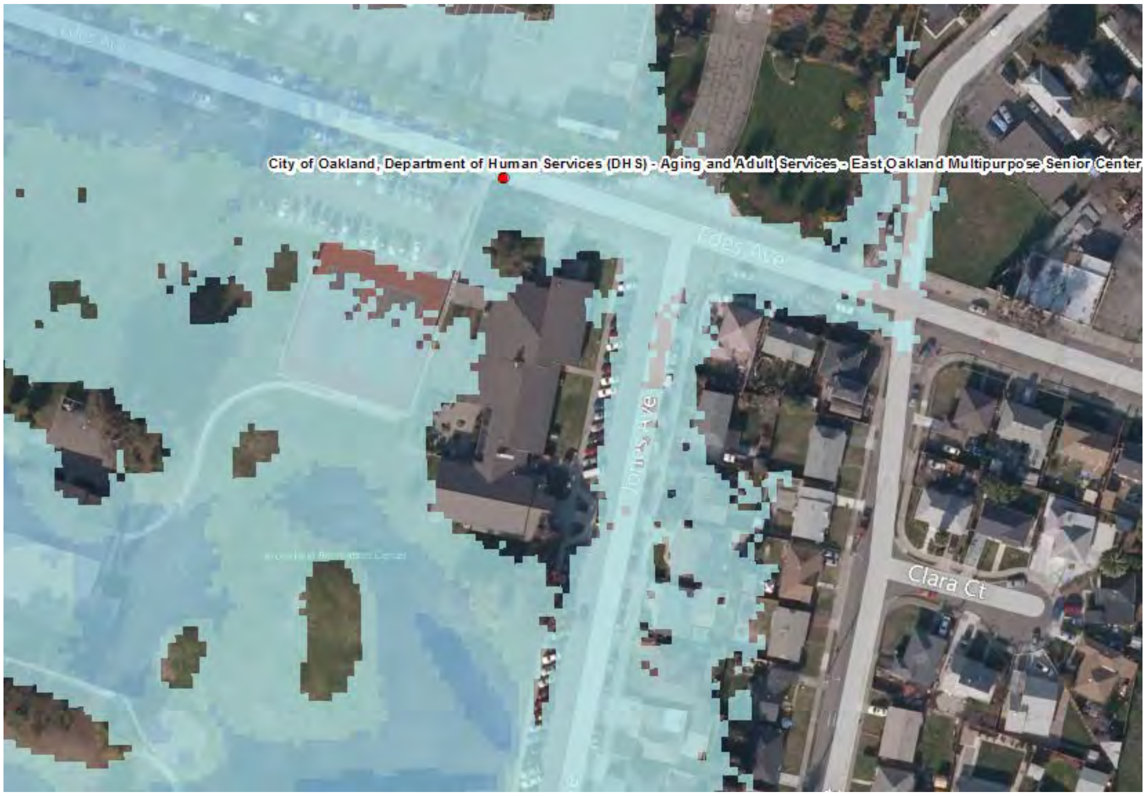


Figure 9 Example of a false positive when doing a simple analysis based on point locations.

The 25m radius is arbitrary. Various assets have different size footprints, thus a single value could not accurately represent all of the features we considered. A diameter of 50 meters (or about 164 feet) approximates the size of a building in the study region. Some buildings, such as single-family residences, may be somewhat smaller, while government buildings may be larger. An example of the points with a 25-m buffer is shown in Figure 10. Note that there are several instances where two or more points very nearly overlap, but have been adjusted so that they are slightly offset from one another. There are over 10 critical facilities (all related to stormwater) that were located at a single point on Embarcadero West between Alice Street and Jackson Street.

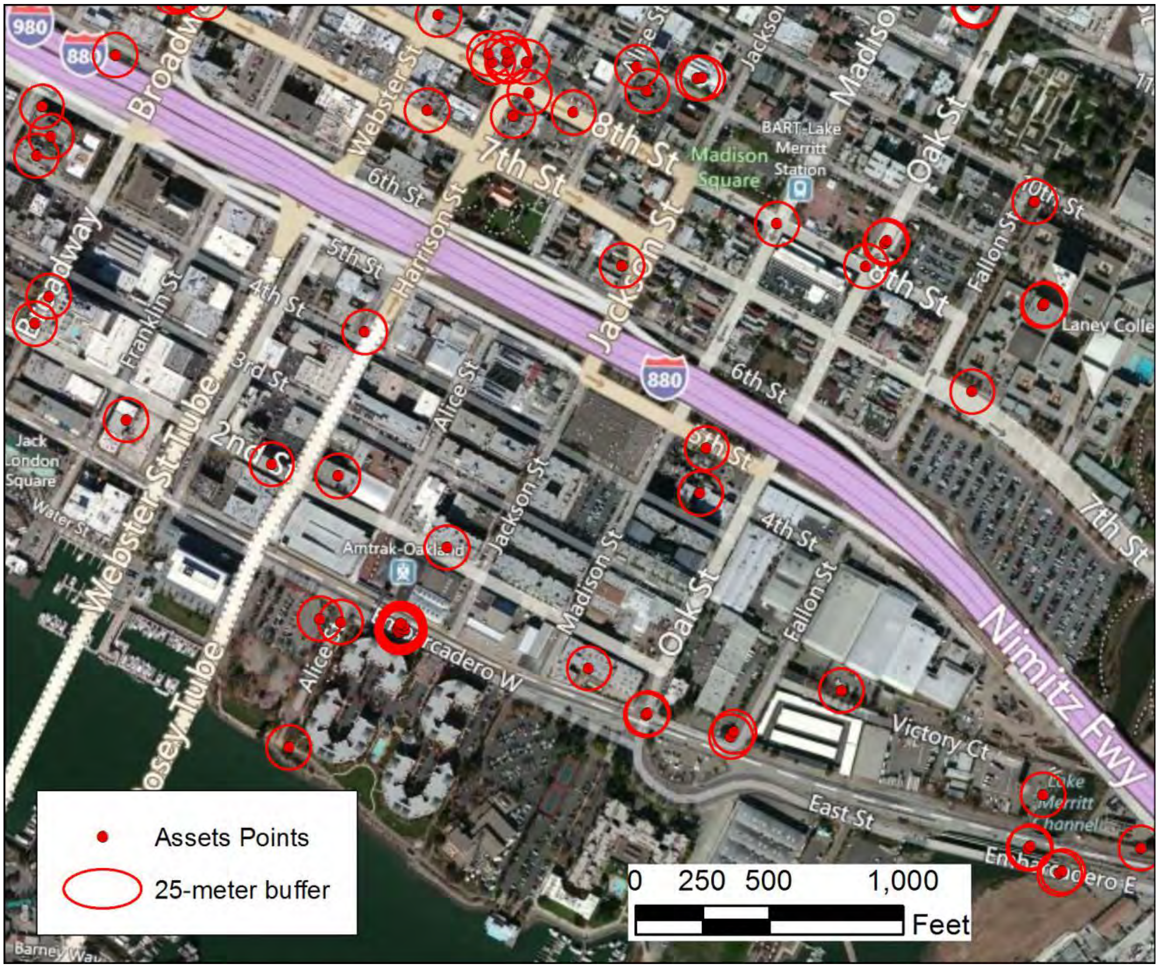


Figure 10 Points in the Community Assets database with a 25-m buffer.

6.2.4 Overlay Analysis

We used the simplified Boolean inundation rasters that we created as described in Section 2.2.3. In these layers, every cell has a value of 1 (flooded) or 0 (not flooded).

We used the ArcGIS Spatial Analyst “Zonal Statistics to Table” tool to summarize the raster values that fell within the 25 m circles representing each facility. The result is the percentage of each circle that is inundated. We considered any circle with a flood percentage greater than zero to be at risk of flooding.

We updated the asset database table to include fields representing the percent inundated and a Boolean (true/false) inundation, using the procedure described in Appendix D. These fields were used when creating Pivot Table summaries of the results in Microsoft Excel.

6.3 Limitations

Various sources were used for gathering data on community assets, the accuracy of which could not be verified. Sources such as 211.org were the best available source for data on service providers such as shelters and emergency food outlets. These sources are intended for connecting clients with services and Pacific Institute could not verify the frequency or methodology with which the information is updated. Some locations for service providers were intentionally withheld by 211.org out of privacy and safety concerns. These include shelters that serve individuals experiencing domestic violence. Some locations of community assets may also be inaccurate due to datasets that include administrative offices rather than solely facilities that directly serve the community.

Some of the data layers that we obtained rely on voluntary reporting by local governments. For example, it appears that some jurisdictions reported many more “critical facilities” than others. Water-related infrastructure for example, appears to be well-represented in the database, but there are fewer entries representing electrical infrastructure or communications. It seems that the definition of “critical” is subjective, making it impossible to fully capture a definitive database of critical facilities.

Lastly, the analysis method simply screens a location for potential flood exposure. It does not address whether individual facilities are elevated above the potential flood elevation or otherwise armored or flood-proofed.

6.4 Findings

The tables below show the number of community assets at risk by city and grouped into four categories. For this analysis, facilities are represented as points in the Geographic Information System.

Table 39 shows the number of assets for each of the six sea-level rise scenarios modeled for the ART project. It appears that there are a large number of critical facilities that are at risk of flooding. This should be tempered somewhat by the observation that the dataset from the Association of Bay Area Governments (ABAG) often included multiple points that are a part of the same facility. For example, there are over a dozen points at the site of EBMUD's wastewater treatment plant in Oakland.

Table 39 Community assets at flood risk in the ART project area sea level rise scenarios

	MHHW		100-yr Stillwater		100-year + Wind & Waves		Total Number of Facilities* (for reference)
	+16"	+55"	+16"	+55"	+16"	+55"	
Community Assets & Vulnerable Populations							
Child Care Facilities	0	12	6	26	26	37	261
Food Banks	0	0	0	2	2	4	31
Group Homes	0	1	0	1	1	1	26
Homeless Shelters	0	0	0	2	2	2	14
Jails	0	0	0	0	0	0	4
Schools	0	12	5	24	24	35	205
Senior Housing	0	18	5	28	28	46	164
Contaminated Sites							
Cleanup Program Sites	12	58	29	97	96	128	291
DTSC-listed sites	2	36	10	68	68	78	108
Leaking Underground Storage Tanks	4	49	17	109	109	142	390
Military Sites	3	60	41	121	121	124	139
RCRA-listed sites	1	51	20	110	110	153	238
Landfills and Waste Facilities	3	8	7	14	14	18	22
Critical Facilities							
Critical Facilities - City and County	10	36	28	58	59	79	128
Critical Facilities - Special District	9	91	39	144	145	154	192
Emergency Response							
Fire Stations	0	3	2	3	3	3	8
Police Stations	0	1	1	3	2	3	13
Health Care							
Health Care Facilities	0	9	3	19	19	25	202
Hospitals	0	0	0	0	0	0	10
Long-Term Care Facilities	0	2	0	7	7	7	52
Total	**44**	**447**	**213**	**836**	**836**	**1039**	**2,498**

*Note that the total number of facilities may not represent all facilities in each study-area city, as discussed in the text.

In Table 40, we show the number of assets exposed to inundation risk by city, with each row showing a different category of community asset. This analysis reflects the number of facilities at risk under the scenario representing the 100-year storm event plus wind and waves, plus a 55" sea-level rise. Tables like this one can easily be produced for each of the six inundation scenarios by making a small change to a Pivot Table in an MS Excel workbook available from the authors.

Table 40 Community assets at risk under the highest scenario of sea-level rise and flooding (100-year storm event plus wind and waves, with 55 inch sea level rise), by category and by community

	Alameda	Emeryville	Hayward	Oakland	San Leandro	San Lorenzo	Union City	Total
Community Assets & Vulnerable Populations								
Child Care Facilities	14	–	2	10	3	4	4	37
Food Banks	1	–	–	3	–	–	–	4
Group Homes	–	–	–	–	–	–	1	1
Homeless Shelters	–	–	–	2	–	–	–	2
Schools	14	–	1	8	4	3	5	35
Senior Housing	12	1	5	3	5	3	17	46
Contaminated Sites								
Cleanup Program Sites	12	6	11	83	9	2	5	128
DTSC-listed sites	6	13	4	52	2	–	1	78
Leaking Undg. Storage Tanks	15	16	16	74	4	4	13	142
Military Sites	114	–	–	10	–	–	–	124
RCRA-listed sites	13	22	39	57	15	1	6	153
Landfills and Waste Facilities	4	2	1	8	2	–	1	18
Critical Facilities								
City and County	27	2	14	29	3	–	4	79
Special District	13	1	11	112	14	–	3	154
Emergency Response								
Fire Stations	1	1	–	1	–	–	–	3
Police Stations	2	1	–	–	–	–	–	3
Health Care								
Health Care Facilities	9	4	2	6	2	–	2	25
Long-Term Care Facilities	7	–	–	–	–	–	–	7
Total	**264**	**69**	**106**	**458**	**63**	**17**	**62**	**1,039**

7 References

Alameda County Office of the Assessor (2012), Secured Roll File (IE670). Oakland, California, January 21, 2012.

Alameda County (2011), Parcel Boundaries in Alameda County GIS Data, Shapefile. Oakland, California. http://www.acgov.org/gis.htm, downloaded Jan 21, 2012.

Association of Bay Area Governments. "Critical Facilities in Hazard Areas – 2005 Data." *ABAG Earthquake and Hazards Program*, November 3, 2010. http://quake.abag.ca.gov/mitigation/cf2005/.

California Department of Finance (2007) *Population Projections by Race / Ethnicity, Gender and Age for California and Its Counties 2000–2050.* http://www.dof.ca.gov/research/demographic/reports/projections/p-3/

Cutter, Susan L., Bryan J. Boruff, W. Lynn Shirley. (2003). Social Vulnerability to Environmental Hazards. Social Science Quarterly, Volume 84, Number 2, June 2003.

Cutter, Susan L., Christopher T. Emrich, Jennifer J. Webb, and Daniel Morath. (2009) Social Vulnerability to Climate Variability Hazards: A Review of the Literature. http://adapt.oxfamamerica.org/?utm_source=redirect&utm_medium=web&utm_campaign=USROSVM

Federal Emergency Management Agency (FEMA). 2006. Hazards U.S. Multi-Hazard (HAZUS-MH). Computer application and digital data files on 2 CD-ROMs. Jessup, Maryland. http://www.fema.gov/plan/prevent/hazus/.

Focus Strategies, Aspire Consulting, and EveryOne Home (2011) *Reports on the 2011 Alameda Countywide Homeless Count and Survey.* Retrieved March 29, 2012, from http://www.everyonehome.org/resources_homeless_count11.html.

Google. "Google Maps/Google Earth APIs Terms of Service." *Google Developers*, April 8, 2011. https://developers.google.com/maps/terms#section_10_12.

Hazards and Vulnerability Research Institute. "SoVI Frequently Asked Questions." University of South Carolina, December 15, 2011. http://webra.cas.sc.edu/hvri/products/sovifaq.aspx.

Heberger, M, H. Cooley, P. Herrera, P. Gleick, and E. Moore. *The Impacts of Sea-Level Rise on the California Coast*. California Energy Commission, Public Interest Energy Research Paper CEC-500-2009-024-F. Oakland, CA: Pacific Institute, 2009. http://pacinst.org/reports/sea_level_rise/report.pdf.

Heinz Center. 2000. *Evaluation of Erosion Hazards.* Report prepared for the Federal Emergency Management Agency. Contract EMW-97-CO-0375. Washington, D.C. http://www.fema.gov/pdf/library/erosion.pdf

Honeycutt D., S. Murray, and G. Prince, "Fundamentals of GIS Analysis: Overlay." Presentation at ESRI International User Conference, July 13-16, 2010, San Diego, California. http://calmap.gisc.berkeley.edu/esri/uc/workshops/tw_614.pdf

IPCC, 2007, *Climate Change 2007: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry, Martin L., Canziani, Osvaldo F., Palutikof, Jean P., van der Linden, Paul J., and Hanson, Clair E. (eds.)]. Cambridge University Press, Cambridge, United Kingdom, 1000 pp. http://www.ipcc-wg2.org/index.html

King P.G., A.R. McGregor, and J.D. Whittet. *The Economic Costs of SeaLevel Rise to California Beach Communities*. San Francisco: California Department of Boating and Waterways and San Francisco State University, 2011. http://www.dbw.ca.gov/PDF/Reports/CalifSeaLevelRise.pdf.

Klynman, Y., N. Kouppari, and M. Mukhier. 2007. *World Disasters Report: Focus on Discrimination*. International Federation of Red Cross and Red Crescent Societies. Switzerland.

Schneider, S. H., S. Semenov, A. Patwardhan, I. Burton, C. H. D. Magadza, M. Oppenheimer, A. B. Pittock, A. Rahman, J. B. Smith, A. Suarez, and F. Yamin. 2007. "Assessing key vulnerabilities and the risk from climate change." In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, Eds. Cambridge, UK: University Press. 779–810. http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm

Hewitt, K. 1997. *Regions of Risk: A Geographical Introduction to Disasters*. London: Addison Wesley Longman.

Knowles, N. "Potential Inundation Due to Rising Sea Levels in the San Francisco Bay Region." San Francisco Estuary and Watershed Science 8, no. 1 (n.d.). http://escholarship.org/uc/item/8ck5h3qn.

NOAA (2000). *Tide and Currents Glossary*. Silver Spring, Maryland. http://co-ops.nos.noaa.gov/publications/glossary2.pdf.

NOAA Coastal Services Center (2011). Social Vulnerability Index (SOVI) Census 2000 Block Groups. Accessed 11/20/11 from http://www.csc.noaa.gov/digitalcoast/data/sovi/.

Travis, W. (2009) "Adaptation: Urban Infrastructure and Climate Change; Lessons from San Francisco Bay." Presentation given at UC Berkeley School of Law, October 3, 2009.

United States Census Bureau (2011) "Changes in the Number of Census Blocks, 2000-2010". http://www.census.gov/geo/www/2010census/changes_census_blocks_2000_2010.pdf.

United Nations. Statistical Division. *Handbook on Geographic Information Systems and Digital Mapping*. United Nations Publications, 2000. http://unstats.un.org/unsd/publication/SeriesF/SeriesF_79E.pdf

Acronyms and Abbreviations

ABAG	Association of Bay Area Governments
APN	Assessor's Parcel Number
ART	Adapting to Rising Tides
BCDC	Bay Conservation and Development Commission
CSC	Coastal Services Center, a division within NOAA
DPH	California Department of Public Health
DTSC	California Department of Toxic Substances Control
EBMUD	East Bay Municipal Utility District
FEMA	Federal Emergency Management Agency
FIPS	Federal Information Processing Standards
GCS	Geocentric Coordinate System
GIS	Geographic Information System
HAZUS	Geographic information system-based natural hazard loss estimation software package developed and freely distributed by the Federal Emergency Management Agency (FEMA).
MHHW	Mean Higher High Water
NAD83	North American Datum of 1983
NOAA	National Oceanic and Atmospheric Agency
RCRA	Resource Conservation and Recovery Act of 1975
SLR	Sea Level Rise
SoVI	Social Vulnerability Index
TSDF	Treatment, Storage, and Disposal Facility
USGS	United States Geological Survey
WWTP	Wastewater treatment plant

Appendix A: "The SoVI Recipe"

Reprinted from Hazards and Vulnerability Research Institute (January 2011). Retrieved March 19, 2012, from http://webra.cas.sc.edu/hvri/docs/SoVI_32_recipe.pdf.

1. Collect the input variables. SoVI variables are derived primarily from the US Census Bureau using the Census Data Engine with some ancillary data from the Geographic Names Information System (GNIS). Alternate data sources may include City and County Databook or individual county offices.

2. Normalize all variables as either percentages, per capita values, or density functions (i.e. 'per square mile').

3. Verify accuracy of the dataset using descriptive statistics (i.e. min/max, mean, standard deviation). Missing values can be replaced by substituting the variable's mean value for each enumeration unit. The statistical procedure will not run properly with missing values. Census units with population valuesof zero should be omitted.

4. Standardize the input variables using z-score standardization. This generates variables with a mean of 0 and standard deviation of 1.

5. Perform the principal components analysis (PCA) using a varimax rotation and Kaiser criterion for component selection. This rotation reduces the tendency for a variable to load highly on more than one factor. Next, set parameters for the extraction of factors. This can be aided by the examination of a scree plot for significant drops in Eigenvalue as the number of components included in the analysis increases. While some disjoints in the scree are anticipated (such as those that occur between the first few components) subsequent decreases in Eigenvalue indicate appropriate thresholds for factor extraction.

6. Examine the resulting factors. Determine the broad representation and influence on (i.e. increase or decrease) social vulnerability for each factor by scrutinizing the factor loadings (i.e. correlation between the individual variable and the entire factor) for each variable in each factor.

7. Factors are named via the choosing of variables with significant factor loadings (or correlation coefficients)--usually greater than .500 or less that -.500. Next, a directional adjustment (or cardinality) is applied to an entire factor to ensure that the signs of the subsequent defining variables are appropriately describing the tendency of the phenomena to increase or decrease vulnerability.

Factor 1 below is an indicator of class and poverty. As shown in the table, the dominant factors that theoretically **increase** vulnerability (people over age 25 w/o a diploma, percent in poverty) have a significant **positive** factor loading. Conversely, the other 2 dominant factors, while still being indicators of socioeconomic status (percent employment and per capita income), theoretically **decrease** vulnerability, and exhibit a **negative** factor loading. Thus, the cardinality of this factor remains positive (+) as the signs on the factor loadings for the individual variables is consistent with their tendency on social vulnerability.

Factor 2 is an indicator vulnerable age groups (i.e. the old and the young). As you can see, both the old and the young, as well as their proxies embody the dominant factors. In examining the variables' factor scores, we see that they exhibit both positive and negative factor loadings, but since all of the variables (i.e. kids under 5, elderly over 65, median age, and social security beneficiaries) have tendency to **increase** vulnerability, we apply an absolute value to Factor 2 to dissolve the negative sign on the factors that increase vulnerability, and maintain the cardinality of the variables with non-negative loadings.

Alternatively, some factors may exhibit significant **positive** factor loadings on variables that theoretically **decrease** vulnerability. Factor 4 below is one such example, with positive loadings on mean rent, mean house value and percent rich. To adjust the sign of this factor so that those variables appropriately represent their tendency to decrease social vulnerability, a negative cardinality is applied, and the factor is multiplied by -1.

8. Save the component scores as a separate file.

9. Place all the components with their directional (+, -, ll) adjustments into an additive model and sum to generate the overall SoVI score for the place.

10. Map SoVI scores using an objective classification (i.e. quantiles or standard deviations) with 3 or 5 divergent classes so illustrate area of high, medium, and low social vulnerability.

Appendix B: Land Use Classification Cross-Reference

Table 41 Cross reference relating land use classification used in this study (BCDC Category) to the land use classifications in the Alameda County Assessor's office database

BCDC Category	Assessor's Land Use Classification (Use Code)
Agriculture	Rural property used for agriculture, 10+ acres
Care Facility	Medical-Residential Care Facility (SFR)
	Assisted living unit
	Nursing or boarding home
	Skilled Nursing Facility
Cemetery	Cemetery
Commercial	One story store
	Commercial Imps on Residential Land
	Miscellaneous improved commercial
	Department store
	Discount store
	Restaurant
	Shopping Center
	Shopping Center-Community
	Shopping Center-NBHD without anchor (strip mall)
	Shopping Center-Power Center
	Commercial or Industrial Condominium
	Commercial or Ind Condo Common Area
	Nurseries
	Church
	Other institutional property
	Lodgehall and/or clubhouse
	Historical commercial
	Church Home
	Car wash
	Commercial repair garage
	Automobile dealership
	Parking lot
	Parking garage
	Service Stations
	Funeral home
	Bank
	Medical - Dental building
	Veterinarian Office
	One to five story office building
	Over five story office building
	Bowling alley
	Walk-in theater
	Drive-in theater
Condominium	Condominiums - single residential living unit
	Condominium - residential live/work unit
	Condominiums - single res unit, first sale
	Condominium - res live/work unit, first sale
	Condominium - single res unit, R&T 402.1
	Condominium Common Area
	Condominium - res live/work, common area or use

	Condominium - urban res unit above, common area or
	Condominium-office, common area or use
Floating Home	Floating home
Golf Course	Golf course
Grocery	Supermarket
Historic Residential	Historical residential
Hospital	Hospital (convalescent or general)
	Medical clinic/outpatient surgery
Hotel	Hotel
Improved Rural	Improved rural land, non-renewal Williamson Act
Industrial	Warehouse
	Warehouse-Self Storage
	Light industrial
	Industrial Flex/R&D use
	Heavy industrial
	Misc. industrial (improved); no other ind code
	Quarries, Sand and Gravel
	Terminals, trucking and distribution
	Wrecking yards
Mixed Use	Store on 1st floor, with offices, apts/lofts 2nd/3
Mobile Home	Mobile home on SFR land
	Mobile home in a mobile home park
	Mobile home park
Motel	Motel
Multi-Family Residential	Planned development - Townhouse
	Townhouse Style - Condominium
	Planned development - Townhouse, R&T 402.1
	Planned Development - Townhouse, Common Area
	Townhouse Style - Condominium, Common Area or use
	Double or duplex type - two units
	Triplex; double or duplex with single family home
	Four living units; e.g. fourplex or triplex w/SFR
	Four residential living units, R&T 402.1
	Res property of 2 units, lesser quality than 2200
	Res property of 3 units, lesser quality than 2300
	Res property of 4 units, lesser quality than 2400
	Res property of 2,3 or 4 units with rooming house
	More than 1 mobile home, or M/H w/other res units
	Vacant apartment land, capable of 5 or more units
	Vacant apartment land, R&T 402.1
	Vacant apartment common area
	Five or more single family res homes
	Residential property converted to 5 or more units
	Restricted residential income property
	Fraternities and sororities
	Multiple residential building of 5 or more units.
	Residential high-rise (7 or more stories)
Public	Exempt Public Agency
	Property leased to a public utility
	Property owned by a public utility
	Vacant land necessary part of institutional prop.
	Government owned property - vacant land

	Improved government owned property
Recreation	Other recreational activity, e.g. rinks, stadiums
Residential	Tract land, R&T 402.1
	Partially complete residential tract home
	Tract residential PC, R&T 402.1
	Residential Imps on Commercial Land
	Residential Imps on Industrial Land
	Condominium-industrial, common area or use
	Live-Work condominium, R&T 402.1
	Cooperatives (divided)
	Cooperatives (undivided)
Rural	Vacant rural-res homesites, may incl misc. imps
	Improved rural-residential homesite.
	One or more mobile homes on rural home site.
	Rural property with significant commercial use
	Rural property with significant industrial use
	Rural property in transition to a higher use
Salt Ponds	Salt Ponds
School	School
Single Family Residential	Single family residential homes used as such
	Single family residential home, R&T 402.1
	Single family residential (tract) common area
	Single family res home with non-economic 2nd unit
	Single family res home with slight commercial use
	Single family res home with slight industrial use
	Single Family Res - Duet Style, R&T 402.1
	Single family res land with/subj. to communal imps
	SFR Detached Site Condominium , Common Area or use
	Single family res home converted to boarding house
	Planned development tract SFR with common area
	Planned development tract SFR, R&T 402.1
	Planned development tract SFR, Common Area
	Modular/manufactured single family res unit (home)
	Two, three or four single family homes
Unknown	Unknown Use
	Secured PI
Vacant Commercial	Vacant commercial land (may include misc. imps)
Vacant Industrial	Vacant industrial land (may include misc. imps)
Vacant Residential	Vacant residential tract lot
	Vacant residential land, zoned 4 units or less
	Vacant residential land, R&T 402.1
Vacant Rural	Vacant rural land, not usable even for agriculture
	Vacant rural land, non-renewal Williamson Act

Appendix C: Excel/VBA Function to Disperse Overlapping Point Coordinates

Below, we list two short functions written in Visual Basic for Applications (VBA) for Microsoft Excel to disperse overlapping points. This code is described in Section 6.2.2.

```
Option Explicit

'The purpose of these two functions was to move overlapping points where
'you have a lat, lng pair. It is analagous to the Disperse Markers tool in ArcGIS.
'The list has to be sorted for it to work properly.
'It is not very sophisticated and could be improved.

Function LatRev(rng As Range, Optional dist As Double = 0.0003)
    Dim i As Long
    Dim mult() As Variant

    mult = Array(0, 0.707, 1, 0.707, 0, -0.707, -1, -0.707, 0)

    i = 0
    Do
      If rng.offset(-i - 1, 0).Value <> rng.Value Then Exit Do
      i = i + 1
    Loop

    LatRev = rng.Value

    If i > 0 Then
      LatRev = LatRev + (1 + Int(i / 9)) * dist * mult(i Mod 9)
    End If
End Function


Function Lngrev(rng As Range, Optional dist As Double = 0.0003)
    Dim i As Long
    Dim mult() As Variant
    mult = Array(1, 0.707, 0, -0.707, -1, -0.707, 0, 0.707, 1)

    i = 0
    Do
      If rng.offset(-i - 1, 0).Value <> rng.Value Then Exit Do
      i = i + 1
    Loop

    Lngrev = rng.Value

    If i > 0 Then
      Lngrev = Lngrev + (1 + Int(i / 9)) * dist * mult(i Mod 9)
    End If
End Function
```

Appendix D: Overlay Analysis Methods

The next several paragraphs describe the steps we used to calculate the proportion of the region's population that is exposed to flood risk. We used a form of geographic analysis called "area-weighted interpolation." For a theoretical overview of this method, see for example the *Handbook on Geographic Information Systems and Digital Mapping* (United Nations Statistical Division 2000, p. 107–112). For this discussion, we use the example of population data which is linked to Census Blocks that are represented as polygons on maps or in a GIS database. However, this same procedure can be used to analyze any variable which is linked to polygons (e.g. parcels).

We begin by using ArcGIS to calculate the percentage of each Census block that is inundated in each scenario. In other words, we are performing a form of overlay analysis to determine what fraction of each Census block is covered by cells in the inundation raster that represents a flooded condition. The methods described here can be used for any variable that is an attached to polygons (e.g. property value, number of low-income households, etc.)

There are a number of possible ways to approach this problem, but we had the most success using the ArcGIS Spatial Analyst tool "Zonal Statistics as Table." The Zonal Statistics tool, "Summarizes the values of a raster within the zones of another dataset and reports the results to a table" according to ESRI's description. The feature zone data is the feature class containing the Census block polygon boundaries. We used the binary floodplain rasters that we created previously (described in Section 2.2.3) as the input raster.

Under Statistics type, we chose MEAN, which "calculates the average of all cells in the value raster that belong to the same zone as the output cell." Because these raster layers contain only two possible values (1 for flooded areas, 0 for dry areas), the average of the 0s and 1s is a value between 0 and 1 that represents the fraction of the Census Block that is covered by floodwaters.

We also checked the option "Ignore NoData in calculations." The meaning of this option is: "Within any particular zone, only cells that have a value in the input Value raster will be used in determining the output value for that zone. NoData cells in the Value raster will be ignored in the statistic calculation." In other words, this tool will ignore all Census blocks that fall outside of the edge of the raster datalayer. It will also not attempt to do a partial calculation for blocks near the edges of the raster. This option is important because the block boundary file covers all of Alameda County, while the flood layers cover only a limited geographic area.

For the zonal statistics tool to give the expected results, it is important to set certain Environment Settings. In ArcToolbox, under Environment Settings Raster Analysis, Cell Size should be set to "Minimum of Inputs." This is because during the analysis, vector files are converted to temporary rasters. To achieve the best accuracy, these temporary rasters should have the same cell size as the input raster. Checking this option ensures that this happens.

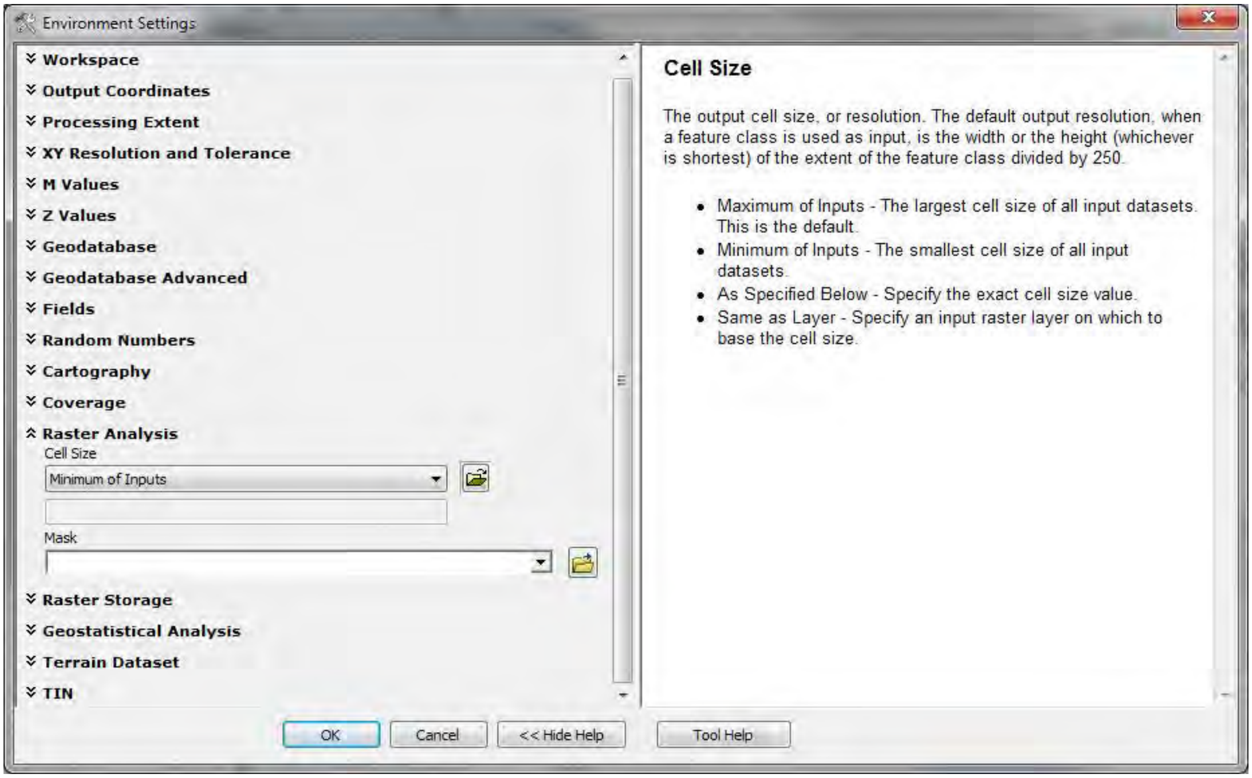


Figure 11 Environment settings dialog box in ArcGIS.

For each zonal statistics calculation, we used the Census block ID code as the Zone Field. The block ID works well because it is a unique identifier that is associated with every Census block in the database. The ID is a 15-digit code that contains all of the information needed to determine its state, county, tract, and block group (Figure 12). Note that these are not numbers, but rather numeric codes that consist entirely of the digits 0–9. Because the codes sometimes start with 0, great care needs to be taken not to import these ID numbers into a spreadsheet or database as a number, or the opening zero will be dropped and valuable information will be lost.

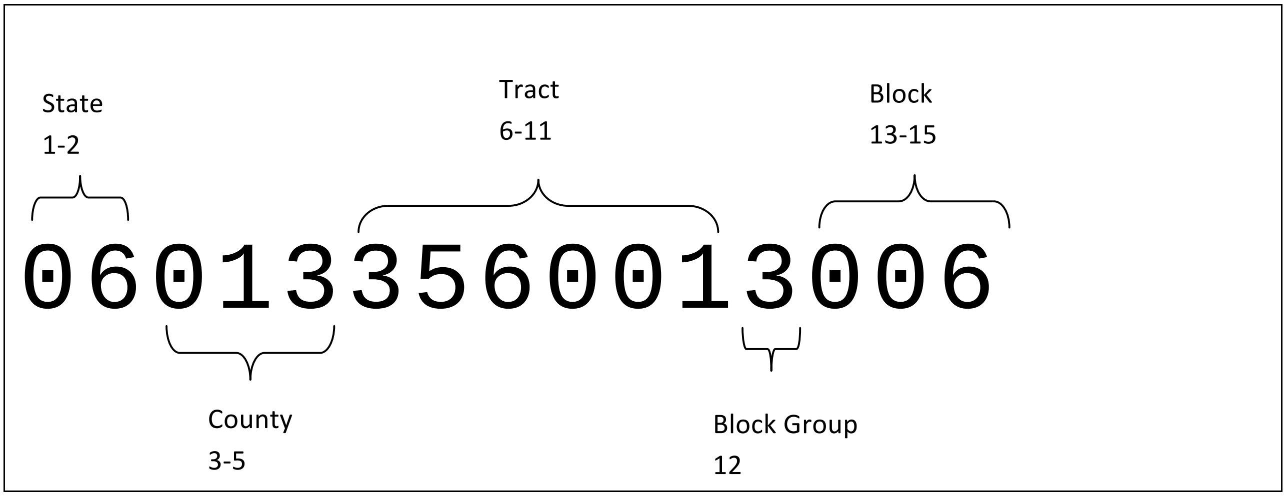


Figure 12 Decoding Census Block IDs.

We repeated the zonal statistics calculation for each of the six flood layers. We stored the output tables in a Microsoft Access database, and carefully named them to avoid confusion. We named the files:

- fld_mhhw16
- fld_mhhw55
- fld_sw16
- fld_sw55
- fld_ww16
- fld_ww55

We then opened the Census block feature class attribute table directly in ArcMap. We created 6 new fields with the same names as the tables above (fld_mhhw16 etc.), with the data type "floating point number." We set up a series of table joins to join the Census block attribute table with the flood percentage table, basing the join on the field representing the Census block ID. We used the ArcGIS Field Calculator to insert the values from the zonal statistics tables into the block attribute table. At this point, we verified that the blocks had been assigned proper values by looking carefully at the layer, as is shown in Figure 4.

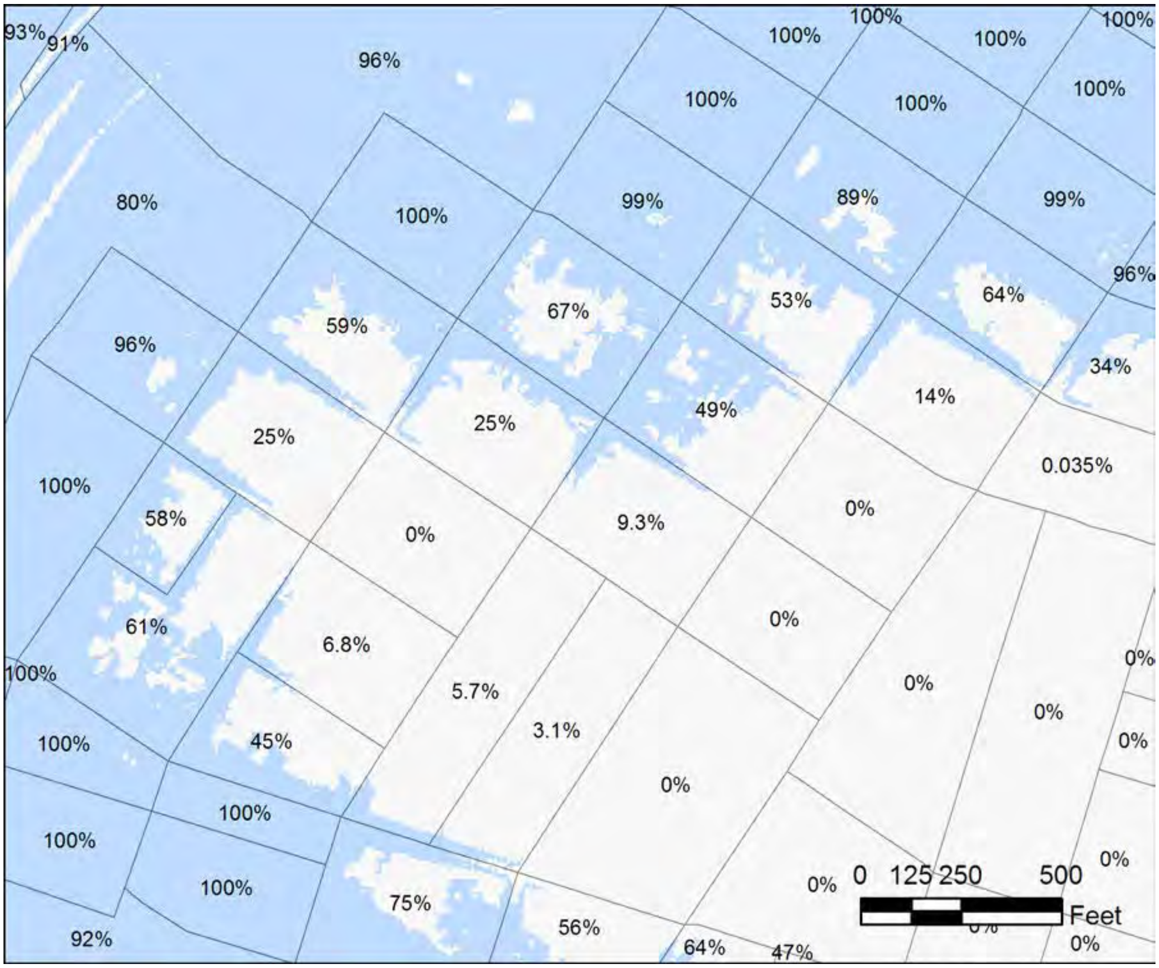


Figure 13 Example of overlay of the flood raster layer (blue shading) with the Census block boundary polygons to determine percent of each block in the study area that is exposed to flooding

After the fields representing flooding were populated, we summarized the data using Pivot Tables in MS Excel. Pivot Tables are a powerful way to analyze and summarize data that is in a tabular or database format. It allows the user to quickly create "cross tabulations," and is a feature that is included in most spreadsheet packages. One of the main advantages to using the older Access-based personal geodatabase format to store geographic feature data is the ability to read data directly in MS Excel and create Pivot Table summaries. Geodatabases and Excel workbooks are available from the authors for analysts wishing to create custom data summaries.

It is important to note that the area-weighted interpolation method of overlay analysis is prone to inaccuracies. It requires one to assume that the variable of interest is evenly distributed within each of the target area's polygons. For example, we assume that the population is evenly distributed over a Census block. This assumption may be a valid approximation in dense urban areas where the housing stock shares similar densities. It is easy to find examples where portions of Census blocks are unpopulated. We partially overcame this difficulty by performing a clip to remove the portion of blocks covered by ocean.

Figure 14 shows an example of a Census Block that is partially flooded. However, the floodwaters are on a golf course and neither buildings nor people appear to be threatened. In this example, the Census Block in Hayward has a population of 580 and is 14.3% inundated. Area-based weighting gives a population exposed to inundation of 83 people. A close look at the inundation zone shows that there are no homes at risk in this Census Block. This is an example of where the area-weighting method *overestimates* the population exposure. Likewise, there are instances where the method is likely to underestimate exposure.

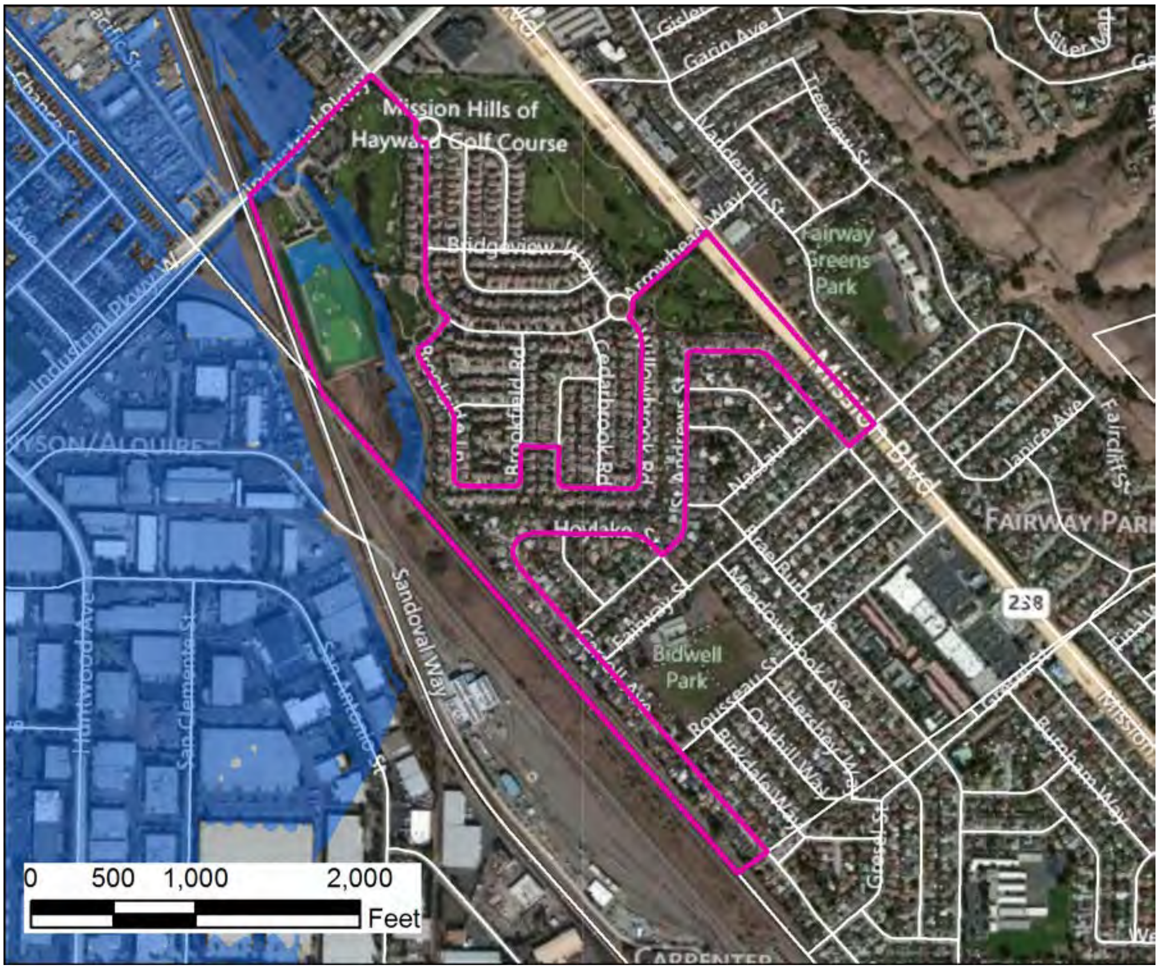


Figure 14 **Example of a partially flooded census block where buildings or population do not appear to be at risk**

Appendix E: Python Script for Batch Geocoding

Below is the listing for a Python program to geocode locations, or get their latitude and longitude coordinates, based on a list of addresses using the Google Maps Geocoding API. Please note that this service was used by permission, and is ordinarily intended for use via interactive websites displaying a Google Map, as described in Google's terms of service (Google 2011). The use of this code is described in Section 6.2.1.

It takes a tab-delimited file with fields for ID, Address, City, State, and Zip Code, like the following in **addresses.txt**:

```
107    35000 Eastin Court        Union City    CA    94587
105    31600 Alvarado Blvd       Union City    CA    94587
112    31600 Alvarado Blvd       Union City    CA    94587
115    3841 Smith Street         Union City    CA    94587
404    1995 Industrial Pkwy West Hayward       CA    94544
359    27836 Loyola Avenue       Hayward       CA    94545
403    1275 W. Tennyson Road     Hayward       CA    94544
```

The script produces a file called **results.txt** with a set of latitude and longitude coordinates keyed to the input ID numbers.

```
107    -122.0696955 37.5658896
105    -122.0730684 37.5917172
112    -122.0730684 37.5917172
115    -122.0776437 37.5966091
404    -122.0755872 37.6176350
359    -122.0923618 37.6251261
403    -122.0788514 37.6314539
```

Here is the Python script:

```
import urllib
import time

def geocode(address):
      # This function queries the Google Maps API geocoder with an
      # address. It gets back a csv file, which it then parses and
      # returns a string with the longitude and latitude of the address.

 # This isn't an actual maps key, you'll have to get one yourself.
```

```
 # Sign up for one here: http://code.google.com/apis/maps/signup.html
      mapsKey = '***APIKEY***'
      mapsUrl = 'http://maps.google.com/maps/geo?q='

 # This joins the parts of the URL together into one string.
      url = ''.join([mapsUrl,urllib.quote(address),'&output=csv&key=',mapsKey])

      #print url
 # This retrieves the URL from Google, parses out the longitude and latitude,
 # and then returns them as a string.
      coordinates = urllib.urlopen(url).read().split(',')

      #Sometimes the google API returns 0...
      #if so, pause for one second and try it again
      print coordinates

      if coordinates[1] == "0":
             print "retrying..."
             time.sleep(1)
             coordinates = urllib.urlopen(url).read().split(',')

      coorText = '%s\t%s' % (coordinates[3],coordinates[2])
      return coorText

h = open('c:/py/addresses.txt', 'r')
o = open('c:/py/results.txt', 'w')

for line in h.readlines():

      data = line.rstrip().split('\t')
      print data[1:]
      address = '%s, %s, %s %s' % tuple(data[1:])
      try:
             tmp = [data[0], geocode(address)]
             o.write( '\t'.join(tmp) )
             o.write('\n')
      except:
             pass
```

Economic Analysis of Recreational and Other Values of Parks in the Adapting to Rising Tides Project Area

The San Francisco Bay Conservation and Development Commission (BCDC), with funding from NOAA Coastal Services Center, has requested that ERG estimate the value of eight low-lying parks along the shoreline of Alameda County, California with respect to what would be lost if they are exposed to impacts of two sea-level rise scenarios at two different timeframes. For simplicity, ERG has assumed that these low-lying coastal parks are lost completely under either sea-level rise scenario (16 and 55 inches). Additionally, ERG has assumed the following: complete loss of the park occurs in both timeframes (2050 or 2100); no mitigating measures are taken to protect the parks; and no slow loss occurs over time. Partial loss scenarios are very difficult to value because of the need to identify at what point a partial loss is a total loss of a park amenity. For example, with a baseball field, losing 10 percent of the field might be considered a total loss of that amenity. On the other hand, losing 10 percent of a wide beach might not be a total loss. We also assume that the park amenities cannot be relocated and no substitutes for the parks are available within a distance that would be willingly traveled by the existing visitors given the amenities provided.

The eight parks studied include (1) Crown Memorial State Beach, (2) Hayward Regional Shoreline, (3) Martin Luther King, Jr. Shoreline, (4) Oyster Bay Regional Shoreline, (5) Estuary Park (including the Jack London Aquatic Center), (6) Union Point Park, (7) Marina Park (in San Leandro), and (8) the Hayward Recreation and Park District (HARD) Hayward Shoreline Interpretive Center and trails.

The general methodology to derive the estimated monetary losses associated with these parks is discussed in Section 1. Section 2 provides the estimates of visitors by park and activity generated using the information provided by park personnel. Section 3 discusses how the unit recreational value of the parks are derived, and Section 4 discusses how all values are aggregated and discounted to create the current year value (present value) of the loss of the eight parks under consideration.

1.0 Overview of the Methodology to Value Losses at Eight East Bay Area Parks

In order to compute the dollar value losses of the eight parks, we need to determine the value of those parks. There are many components to the value of a park, some of which can be easily monetized, but many others are more difficult to assess, such as the value to park visitors of their recreational experience. ERG is focusing on three types of value components that can be assessed given the information provided. The components that were provided are the revenues collected by the parks and the replacement value of the structures and infrastructure of the parks. Also provided were the number of visitors to the parks, which we combine with the estimated value a visitor receives when that visitor uses one or more of a park's amenities, to estimate the recreational value of the park to all of its visitors. Other components of park value are not discussed here, such as the revenues to local businesses that abut the parks and the value of open space to the nearby residents.

The revenues and replacement values of park structures have been provided by BCDC. Numbers of visitors have also been provided in some cases, or have been estimated based on information provided.

Additionally, in most cases, we have been provided with the percentage breakdown of the activities in which the park visitors are involved.

The methodology for determining the value of those activities to the park visitors is as follows. Given the number of park visitors for each of the eight parks and the percentage of visitors undertaking each type of activity as specified, ERG determined the numbers of visitors by park and by activity for 17 different activities (See Section 2 for more details). These are:

- Hiking
- Running
- Walking
- Hiking/Running/Walking
- Beach/Swimming
- Visitor Center/Interpretive
- Picnicking
- Biking
- Special Events
- Sports
- Volunteer Activities
- Dog Walking
- Bird Watching
- Wildlife Viewing
- Kayaking/Canoeing
- Boating
- Playground

ERG then determined an appropriate value for each activity on a per-visitor basis, that is, what would a typical visitor be willing to pay to engage in the activity offered by the park. This willingness to pay is a measure of the value of that park to that visitor on that day. The method used to identify these appropriate values is discussed in Section 3, below.

We then multiply the number of visitors engaged in an activity at a park by the per-visitor unit value of that activity to estimate the value of that activity at that park. When all activities at a park are valued, the total value of the park to its visitors is estimated. This total recreational value is the value for one year's recreation for all visitors at that park.

Assuming that this recreational value for a park remains constant over time, we then assume that all of this value is lost in year 2050 or 2100. The loss of value occurs in every year thereafter (i.e., no replacement for the park is available). We further assume that revenues, to the extent they are incremental to the value of lost recreation, are also lost in 2050 or 2100. We assume this loss continues out every year thereafter. Finally, we assume that the replacement value of the structures at the parks is lost in 2050 or 2100 (a one-time loss). Because these losses occur many years out and some continue to occur in every year after the assumed 100 percent loss in either 2050 or 2100, we need to create a present value analysis.

A present value analysis is used because the value of a dollar today is worth more than a dollar in the future. This concept underlies the reason that interest is charged on loans. We use a discount rate (similar to an interest rate) of 3 percent, based on recommendations by the Office of Management and Budget. This agency, which is responsible for overseeing regulatory analyses issued by Federal agencies, suggests that an appropriate discount rate for public goods is 3 percent per year (OMB, 2003). That is, a dollar today of a public good is worth \$0.97 next year, \$0.94 the following year, \$0.89 the year after that, etc. So a loss occurring 38 years from now (2050) in present value terms would be calculated as \$ Value of Loss/$(1 + 0.03)^{38}$. Although this equation reduces a one-year loss 38 years hence by about two-thirds compared to a loss occurring now, many of the losses continue to occur in every year after the 2050 or 2100 assumed inundation (assuming no substitute for the parks is available). We analyze these losses under both timeframes out to 2161. Analyzing farther into the future adds little to the losses in present value terms.

When all losses are arrayed over the timeframe from 2012 to 2161 and discounted, we can aggregate the present value losses by park and over all eight parks to estimate the total losses for all parks analyzed.

2.0 Counts of Visitors by Activity

Table 1 presents information that arrays the numbers of visitors that visit the park each year and the percentage of those visitors engaging in the activities listed above. Certain assumptions needed to be made because of a lack of data. These assumptions can be seen in the footnotes to the table and, for the HARD Interpretive Center and Trails, in Table 2. The information for the HARD Interpretive Center and Trails was provided only generally by numbers of visitors per day or per week. The estimated annual counts of visitors and the distribution of visitors by activities are shown in both Tables 1 and 2, along with the information provided and additional ERG assumptions made using that information. As Table 1 shows, combinations of hiking, running, and walking, biking, and picnicking appear to be the most common activities at many of the eight parks, with several offering special amenities, such as boating, kayaking and canoeing, swimming, and sports fields.

Using the distribution of activities and the total numbers of visitors shown in Table 1, Table 3 calculates the total numbers of visitors each year by activity. As the table shows, about 1.7 million visitors visit these eight parks each year. The largest numbers of visitors (more than half) visit Crown Memorial State Beach and Martin Luther King, Jr. Shoreline. A large portion of visitors walk, run, or hike; bike; picnic; visit nature/interpretive centers; or swim.

All of these visits have a value to the visitor that can, in some cases, be monetized. Section 3 discusses how these values can be identified and how the value of all visits can be estimated for each park.

3.0 Per-Visitor Recreational Values

There are several methods for estimating the recreational value of parks on a per-visitor basis. Typically, these methods include:

1) The travel-cost method. The cost to travel to a park is an indication of an individual's willingness to pay for the use of that park.
2) The contingent valuation method. Through a series of questions, park goers' willingness to pay for the use of that park is elicited.

3) The unit-day method. This method uses a value estimated using a combination of professional judgment, travel cost studies, and/or contingent valuation studies to derive a value per visit to a park.

The travel-cost method can be less appropriate for urban parks, many of which are walking distance or very short distances from nearby residents, who are likely to comprise a major portion of the park visitors. This valuation method could lead to an understatement of residents' willingness to pay to use a specific park and does not allow for a convenience factor to be valued. Furthermore, performing site-specific contingent valuations or travel-cost surveys of the eight parks under study is beyond the scope of this analysis. Therefore, we need to rely on some form of unit-day method.

Many travel cost and contingent valuation studies focusing on the types of activities that can be provided by parks, including picnicking, biking, hiking, wildlife viewing, and other similar types of activities, have been performed throughout the country. An excellent compilation of these studies is the one prepared by Dr. Randall Rosenberger, which uses 352 studies to create use values for dozens of recreational activities that can be selected and/or averaged to create unit-day values by specific activity and in specific regions (in some cases) (Rosenberger, 2011). Of particular utility is that the database provides values in consumer surplus terms, which means the values cited are those beyond the fees paid by those participating in the park activities. Therefore, the values calculated can be added to any data on fees collected by the East Bay parks. Unfortunately, the vast majority of the studies in the database have been performed in rural or wilderness area parks, where people tend to spend an entire vacation period, travel long distances to visit, and which have, in some cases, very high willingness to pay values associated with them.

Urban parks do not offer the same types of aesthetic experiences as those reflected in most of the studies compiled by Dr. Rosenberger. However, it is important to note that while urban parks might not offer the aesthetic experience, the willingness to pay for urban park amenities could actually be much greater than values calculated for rural areas. This is because of the potential scarcity of open space or outdoor recreational opportunities, travel cost savings, and sometimes greater capital investment and specialized amenities offered by urban parks. These potentially higher values, nevertheless, need to be tempered with consideration of the possibility of larger numbers of potential substitutes, congestion, and lowered environmental quality (Stynes, undated).

Another source for unit-day values for urban parks is a report issued in 2000 commissioned by the East Bay Regional Park District. The value of this study is that it reflects recreational unit-day values that the Park District selected based on their detailed knowledge of the park amenities and their assessment of various willingness to pay studies, which they had determined were applicable. The drawbacks of this study are that the many of the unit-day values selected reflect the per-person fees in effect at the time. Most of these fees are subsidized and it is very likely that actual willingness to pay is higher than the fees actually paid. The actual consumer surplus for the some of the activities valued cannot be determined and have been effectively set at $0.

Another possible source of unit-day values is a U.S. Army Corps of Engineers (USACE) series of reports. The unit-day values in this series are updated by the Corps annually, and the values in 2011 dollars are available (USACE, 2012).[1] The unit-day values span a wide range, but the methodology that can be used

[1] These unit-day values are used by USACE in evaluating their own projects related to recreational areas.

with these values is somewhat flexible. Each park can be assigned points based on a number of different criteria. Higher points are available to assign to parks for those with more amenities and services, for example, or for those that provide substantially greater aesthetic experiences than the average. Additionally, if use statistics by activity are available, the activity by itself can be valued independently from other activities. There are also multiple point systems and values depending on, for example, whether general recreational activities are being assessed (e.g., walking, running, or biking), or whether specialized recreational activities are being assessed. Stynes [undated], for example, recommends using these specialized values for golf courses and zoos. We believe the HARD Interpretive Center and the Crab Cove Visitor Center (at Crown Memorial State Beach) fit this description and, possibly, Crown Memorial Beach. This beach is a unique asset, given the rarity of easy access to true beach facilities from inner city locations.

We investigated all of the values generated for each of the activities identified for the eight parks presented in these three sources. Table 4 provides the list of values derived using the Recreational Values Database. This source provided values for 12 of the activities of interest in this analysis. The average values shown are generally the average values for Western U.S. studies (see footnote 1 in the table). The best estimate values have been selected using judgment about which studies are most applicable to the type of activity offered by the parks in this analysis. The rationale for the selection of the best estimates is also provided in the table footnotes.

Table 4 also presents the list of values ERG derived using the Army USACE report on unit-day values and the methods that the Corps uses to estimate representative general and specialized recreational values for parks when specific surveys are not available. These are willingness to pay values, that is, they are not recreational values above fees paid (consumer surplus).[2] As noted earlier, the unit-day values provided by the USACE report (2012) are used with a points system to define the relative desirability of the various park amenities. Table 5 presents the unit-day values associated with a park's aggregate points, and Table 6 reproduces the USACE's guidance for assigning points to general recreational activities. Guidance is similar for assigning points for specialized recreational activities, but is not reproduced here. Table 7 presents ERG's assignment of points. These assignments are somewhat subjective, and should be reviewed by those more knowledgeable of the park amenities to ensure the points are reasonably estimated. Because ERG only has a general impression of the parks from information provided by park system personnel and online photos and discussion of park amenities, we have tended to assign points conservatively and generically. Thus the sum of points for each of the eight parks is estimated to lie generally within the same range (26-42), and the value of a visitor day for each park (with the exception of two activities present at only two parks—nature center and swimming/beach) does not vary by park or activity using this source of unit values. When the specialized amenities for Crown Memorial State Beach and the HARD Interpretive Center are considered, ERG estimates that the specialized amenities raise the point value for these parks, which lies in the range of 39-55. This point range is then matched to the values for specialized recreation as shown in Table 5.

The values obtained from the last source of unit-day values ERG reviewed, the East Bay study (East Bay Regional Park District, 2000), have been updated to 2011 dollars. Table 7 shows the values presented in

[2] USACE (2000), in the document that originally compiled the unit-day value estimates, states: "unit day value does include entry and use fees actually paid for the site. Therefore, entry and use fees should not be added to the unit day value to determine total willingness to pay."

the report inflated to 2011 values. Many of these values are roughly in the same range as those generated using the Army Corps of Engineers values and approach. They are willingness to pay values that sometimes use fees paid as the measure of the willingness to pay, thus might understate actual willingness to pay because park fees are subsidized and because some visitors might have been willing to pay much more for the activity than they actually did pay.

Table 4 also shows which values were chosen to be used in the analysis for each activity. The values chosen are from the East Bay study or the Army Corps of Engineers, but also generally tend to reflect central values seen for the activity listed among the three sources when a best estimate from the Recreational Values Database was considered available for an activity. We avoided using the Recreational Values Database values because of the relatively high values associated with the activities. Relatively high values persisted even after ERG eliminated studies that clearly were not representative of the parks in our analysis. We considered the best estimates values we derived from this database to reflect a high end of a reasonable values range.

4.0 Results

ERG used the number of visitors per year by activity estimated in Table 3 and applied the chosen unit-day values from Table 4 by activity. Table 8 presents the recreational values by activity for each park and also aggregates the values by park and activity. As the table shows, the total recreational value of all eight parks is estimated at over $17 million per year in 2011 dollars. The recreational value of Crown Memorial State Park makes up about half this estimate. MLK, Jr. Shoreline offers the next largest portion of recreational value among the eight parks.

Additional to the recreational value of the parks are the revenues and replacement costs for park structures. Table 9 presents the data provided by BCDC on replacement cost and revenues generated at the eight parks in the analysis.

ERG then determined the discounted present value of losing the eight parks in 2050 and 2100. We assume all losses are complete, occur in the year considered and that no substitutes exist for the amenities offered by these parks. A no-substitutes scenario could occur if the parks cannot be relocated, which is likely, or if similar amenities are located at too far a distance and/or are of a much poorer quality such that the cost to reach a replacement park is greater than the willingness to pay for that replacement park's amenities of all current visitors to the eight parks in question.

Included in these estimates are the replacement costs of the parks. As noted, ERG was also provided the revenues generated by the parks. However, because the unit-day values we used reflect the total willingness to pay (including fees paid) and not consumer surplus, revenues cannot be combined with these values. Had we selected values from the Recreational Values Database, however, the revenues could have been added to the recreational values estimated because those values reflect consumer surplus (what visitors would be willing to pay above fees paid).

Table 10 presents the dollar value lost when the parks are inundated in 2050 or 2100 (in 2011 dollars). As the table shows, the total dollar value lost when the parks are inundated in 2050, assuming 100 percent loss and no suitable substitutes for those activities, is about $190 million, whereas when the loss occurs in 2100, the total dollar value lost is much less, about $38 million. This reduction in value occurs because the losses are assumed to occur very far in the future, leaving many more years for residents and other visitors to continue to enjoy the park amenities.

References

East Bay Regional Park District, 2000. Regional Economic Analysis (Trends, Year 2000 & Beyond). Prepared for East Bay Regional Park District by Economic & Planning Systems, Inc. in association with Strategy Research Institute. November.

Office of Management and Budget, 2003. Circular A-4. Regulatory Analysis. September.

Rosenberger, Randall S., 2011. Recreation Use Values Database. Public Version. August.

Stynes, Daniel J., undated. Calculating the Value of Direct Use.

USACE, 2012. Economic Guidance Memorandum 12-03. Unit Day Values for Recreation for Fiscal Year 2012.

USACE, 2000. Planning Guidance Notebook. ER 11-05-2-100. April.

Table 1. Visitor Days and Activity Breakdown for Eight Parks

Park	Crown Memorial State Beach	Hayward Regional Shoreline	MLK, Jr. Shoreline	Oyster Bay Regional Shoreline	Estuary Park (1)	Union Point Park (1) (2)	Marina Park (3)	HARD Interpretive Center & Trails (4)
Total Visitor Days	682,022	80,308	514,854	165,033	15,000	2,500	260,000	9,175
Hiking				50%				
Running								
Walking					10%	70%	25%	
Hiking/ Running/Walking	38%	35%	45%					10%
Beach	19%							
Visitor Center/ Interpretive	14%					5%		67%
Picnicking	12%		15%	25%		15%	35%	
Biking	7%	25%	20%	25%	10%		25%	10%
Special Events	4%		5%		10%	5%		
Sports	3%				55%	5%	5%	
Volunteer Activities	3%							
Dog Walking		35%						
Bird Watching		5%						
Wildlife Watching								13%
Kayaking/Canoeing			10%		15%			
Boating			5%					
Playground							10%	
	100%	100%	100%	100%	100%	100%	100%	100%

(1) Assume "passive use" equivalent to walking

(2) Assume "special events and activities" at 30% means 15% picnicking (bbq grills and tables available), 5% interpretive (interpretive center is present), 5% special events, and 5% sports (ball field present).

(3) Marina Park appears to be predominantly a picnic area, but includes playgrounds, a sand volleyball court, and walking and biking trails. Assume 10% playground, 5% sports, 35% picnicking, 25% walking and 25% biking. Numbers of visitors calculated by ERG using the following information: Provided by park system: spring/summer = 700/weekday, 3,000 per weekend; fall/winter = 400/weekday, 1,000/weekend. Calculation is (26 weeks * 5 days * 700) + (26 weeks*3000) + (26 weeks*5*400) + (26 weeks*1000).

(4) See assumptions in Table 2.

Source: Information provided by BCDC and ERG estimates.

Table 2. Assumptions Used to Calculate Visitors and Activities at HARD Interpretive Center and Trails

Information Provided	ERG Assumptions Made	Calculation of Total Visitors and % Activities
Interpretive Center		
Open Wed-Sun.		
Spring weekdays, 35-40 children, 10-15 adults	50 visitors/day, 13 weeks, 3 weekdays per week	1,950
Spring and Summer weekends, 20-50 per day	35 visitors/day, 26 weeks, 2 weekend days per week	1,820
Summer weekdays, 20-50 per day	35 visitors/day, 13 weeks, 3 weekdays per week	1,365
Winter--no data (less use)	20 visitors/day, 26 weeks, weekends only, 2 days	1,040
Total center visits		6,175
Trails		
Trail visits--several thousand	3,000	3,000
Total visits center plus trail		9175
% Center/nature study		67%
%Trail activities		33%
Wildlife viewing	40%	13%
Running/walking/ hiking	30%	10%
Biking	30%	10%

Source: Information provided by BCDC and ERG estimates.

Table 3. Total Numbers of Visitors by Park and Activity

Park	Crown Memorial State Beach	Hayward Regional Shoreline	MLK, Jr. Shoreline	Oyster Bay Regional Shoreline	Estuary Park	Union Point Park	Marina Park	HARD Interpretive Center & Trails	Total Visitors
Hiking	0	0	0	82,517	0	0	0	0	82,517
Running	0	0	0	0	0	0	0	0	0
Walking	0	0	0	0	1,500	1,750	65,000	0	68,250
Hiking/ Running/Walking	259,168	28,108	231,684	0	0	0	0	900	519,860
Beach/ Swimming	129,584	0	0	0	0	0	0	0	129,584
Visitor Center/ Interpretive	95,483	0	0	0	0	125	0	6,175	101,783
Picnicking	81,843	0	77,228	41,258	0	375	91,000	0	291,579
Biking	47,742	20,077	102,971	41,258	1,500	0	65,000	900	279,448
Special Events	27,281	0	25,743	0	1,500	125	0	0	54,649
Sports	20,461	0	0	0	8,250	125	13,000	0	41,836
Volunteer Activities	20,461	0	0	0	0	0	0	0	20,461
Dog Walking	0	28,108	0	0	0	0	0	0	28,108
Bird Watching	0	4,015	0	0	0	0	0	0	4,015
Wildlife Watching	0	0	0	0	0	0	0	1,200	1,200
Kayaking/Canoeing	0	0	51,485	0	2,250	0	0	0	53,735
Boating	0	0	25,743	0	0	125	0	0	25,868
Playground	0	0	0	0	0	0	26,000	0	26,000
Total Visitors	682,022	80,308	514,854	165,033	15,000	2,500	260,000	9,175	1,728,892

Source: Table 1.

Table 4. Unit-Day Values for Recreational Activities

Activity		Recreation Use Values Database (1) (4) (updated to $2011)	Army Corps Unit Day Values (2) ($2011)	East Bay Regional Park District 2000 Report (updated to $2011) (3)	Chosen Value
Hiking	low/BE	$10.69	$5.24	$2.62	$6.11
	avg	$57.21	$6.11	$5.90	
	high		$6.98	$9.17	
Running	low/BE	$4.73	$5.24	$2.62	$6.11
	avg		$6.11	$5.90	
	high		$6.98	$9.17	
Walking	low/BE	NA	$5.24	$2.62	$6.11
	avg	$17.99	$6.11	$5.90	
	high		$6.98	$9.17	
Hiking/ Running/ Walking	low/BE	$10.86	$5.24	$2.62	$6.11
	avg	$56.67	$6.11	$5.90	
	high		$6.98	$9.17	
Beach/ Swimming	low/BE	$40.29	$19.78		$21.64
	avg	$51.03	$21.64	$5.90	
	high		$23.51		
Visitor Center/ Interpretive	low/BE	NA	$19.78	$32.75	$32.75
	avg	$13.18	$21.64		
	high		$23.51		
Picnicking	low/BE	$10.08	$5.24		$6.55
	avg	$19.63	$6.11	$6.55	
	high		$6.98		
Biking(1)	low/BE	$13.86	$5.24		$6.11
	avg	$43.95	$6.11		
	high		$6.98		
Special Events	low		$5.24		$9.83
	avg		$6.11	$9.83	
	high		$6.98		
Sports	low		$5.24		$6.11
	avg		$6.11		
	high		$6.98		
Volunteer Activities	low		$5.24		$6.11
	avg		$6.11		
	high		$6.98		
Dog Walking	low		$5.24		$6.11
	avg		$6.11	$3.28	
	high		$6.98		
Bird Watching	low		$5.24		$6.11
	avg	$51.23	$6.11		
	high		$6.98		
Wildlife Watching	low/BE	$48.54	$5.24		$6.11
	avg	$65.91	$6.11		
	high		$6.98		
Kayaking/ Canoeing	low/BE	$47.72	$5.24	$17.03	$26.20
	avg	$115.48	$6.11	$26.20	

Table 4. Unit-Day Values for Recreational Activities

Activity		Recreation Use Values Database (1) (4) (updated to $2011)	Army Corps Unit Day Values (2) ($2011)	East Bay Regional Park District 2000 Report (updated to $2011) (3)	Chosen Value
	high		$6.98	$52.40	
	low/BE	$22.79	$5.24	$17.03	
	avg	$50.01	$6.11	$26.20	$26.20
Boating	high		$6.98	$52.40	
	low		$5.24		
	avg		$6.11		$6.11
Playground	high		$6.98		

BE=Best Estimate--Applies only to Recreation Values Database

(1) Recreation Use Values Database (Rosenberger, 2011): Average values shown are based studies reflecting the Western U.S. region and reflect means for the activities identified, with the exception of a) biking, which has no studies available for the Western U.S. Region; the overall U.S. average is used for biking; b) birdwatching, data averaged over all studies (U.S. and Canada); one CA study is in the San Joaquin Valley and is higher than the overall average; overall average used for a conservative estimate; c) Running consists of one study (U.S.). All other running studies are for Pikes Peak; d) Walking consists of one study (U.S.). No others are available in database; e) Hiking/Running/Walking average is the average of all running studies in the Western U.S. Regions plus the one walking study plus all Western U.S. Hiking; f) visitor center/interpretive is the mean of one "visiting nature center" study and one study characterized as "nature study"; g) Beach/Swimming is Western U.S. Beach and Western U.S. Swimming averaged. All values have been updated to $2011 using the Consumer Price Index (CPI). See footnote 4 for values used as Best Estimates.

(2) Unit Day Values for Recreation, Fiscal Year 2011 (USACE, 2012): The values for general recreation are assigned based on ratings of each park's recreational experience, availability of the other similar opportunities nearby, the carrying capacity, accessibility, and environmental quality (see Table 5). Each park was individually assessed, but the values for parks for their general recreation attributes fell within similar ranges, leading to uniform values per unit day for each activity. The two exceptions are beach and nature center, two specialized activities given the urban nature of these parks. We deemed that beach access in an urban area was unusual, and was thus a specialized attribute. "Nature center" is similar to the types of specialized activities noted by Stynes (undated) that should receive a higher valuation. A high, low, and average are given for both the general recreation activities and the specialized activities.

(3) East Bay Regional Park District (2000): Values have been updated from $2000 to $2011 using the CPI.

(4) Best estimates for values from the Recreation Values Database are derived as follows:

Hiking: Hiking/CA/Nonwilderness

Running: Running/USA (one study)

Hiking/Running/Walking: Average of Hiking/CA/Nonwilderness, Running/USA (one study) and all (one) walking study

Picnicking: CA/Nonwilderness

Beach/Swimming: Cabrillo-Long Beach CA beach values (4 studies) plus one study of CA swimming, averaged

Biking: Urban/Suburban rail trail in Washington DC area

Wildlife viewing: CA/Nonwilderness

Kayaking/Canoeing: Floating/Rafting/Canoeing: removed whitewater and tubing/rafting (average contains studies characterized as non whitewater kayaking/canoeing/rafting and rowing/other boating

Boating: Western U.S. without AK and with one extreme outlier removed.

Table 5. Values Associated with Specific Points Values Assigned to Parks

Point Values	General Recreation Values	Specialized Recreation Values
0	$3.72	$15.13
10	$4.42	$16.06
20	$4.89	$17.22
30	$5.58	$18.62
40	$6.98	$19.78
50	$7.91	$22.34
60	$8.61	$24.67
70	$9.08	$29.79
80	$10.01	$34.67
90	$10.70	$39.56
100	$11.17	$44.21

Source: USACE, 2012.

Table 6. Unit-Day Method Point Assignments Reproduced from USACE (2012)—Table 1: Guidelines for Assigning Points for General Recreation Criteria

Criteria	Judgment Factors				
Recreation experience[1] Total Points: 30 Point Value:	Two general activities[2] 0-4	Several general activities 5-10	Several general activities: one high quality value activity[3] 11-16	Several general activities; more than one high quality value activity 17-23	Numerous high quality value activities; some general activities 24-30
Availability of opportunity[4] Total Points: 18 Point Value	Several within 1 hr. travel time; a few within 30 min. 0-3	Several within 1 hr. travel time; none within 30 min. 4-6	One or two within 1 hr. travel time; none within 45 min. 7-10	None within 1 hr. travel time 11-14	None within2 hr. travel time 15-18
Carrying capacity[5] Total Points: 14 Point Value	Minimum facility for development for public health and safety 0-2	Basic facility to conduct activity(ies) 3-5	Adequate facilities to conduct without deterioration of the resource or activity experience 6-8	Optimum facilities to conduct activity at site potential 9-11	Ultimate facilities to achieve intent of selected alternative 12-14
Accessibility Total Points: 18 Point Value	Limited access by any means to site or within site 0-3	Fair access, poor quality roads to site; limited access within site 4-6	Fair access, fair road to site; fair access, good roads within site 7-10	Good access, good roads to site; fair access, good roads within site 11-14	Good access, high standard road to site; good access within site 15-18
Environmental Total Points: 20 Point Value	Low esthetic factors[6] that significantly lower quality[7] 0-2	Average esthetic quality; factors exist that lower quality to minor degree 3-6	Above average esthetic quality; any limiting factors can be reasonably rectified 7-10	High esthetic quality; no factors exist that lower quality 11-15	Outstanding esthetic quality; no factors exist that lower quality 16-20

[1] Value for water-oriented activities should be adjusted if significant seasonal water level changes occur.

[2] General activities include those that are common to the region and that are usually of normal quality. This includes picnicking, camping, hiking, riding, cycling, and fishing and hunting of normal quality.

[3] High quality value activities include those that are not common to the region and/or Nation, and that are usually of high quality.

[4] Likelihood of success at fishing and hunting.

[5] Value should be adjusted for overuse.

[6] Major esthetic qualities to be considered include geology and topography, water, and vegetation.

[7] Factors to be considered to lowering quality include air and water pollution, pests, poor climate, and unsightly adjacent areas.

Table 7. ERG Estimates of Point Values for Parks in the Analysis

Park	Criteria	Recreation Experience	Availability of Opportunity	Carrying Capacity	Accessibility	Environmental	Total Points
Crown Memorial State Beach	min	5	0	3	15	3	26
	max	10	3	5	18	6	42
Hayward Regional Shoreline	min	5	0	3	15	3	26
	max	10	3	5	18	6	42
MLK, Jr. Shoreline	min	5	0	3	15	3	26
	max	10	3	5	18	6	42
Oyster Bay Regional Shoreline	min	5	0	3	15	3	26
	max	10	3	5	18	6	42
Estuary Park	min	5	0	3	15	3	26
	max	10	3	5	18	6	42
Union Point Park	min	5	0	3	15	3	26
	max	10	3	5	18	6	42
Marina Park	min	5	0	3	15	3	26
	max	10	3	5	18	6	42
HARD Interpretive Center & Trails	min	5	0	3	15	3	26
	max	10	3	5	18	6	42

Note: For Crown Memorial State Beach and HARD Interpretive Center and Trails, the points selected reflect recreational values that are associated with other activities than the beach/swimming or nature center. In relation to these two activities, we assigned points ranging from 11-16 for recreation experience and 7-10 for availability of opportunity. The other values remain the same, but we apply the values for specialized activities to the sum of the points range generated (points for these two activities sum to 39-55).

Source: ERG estimates.

Table 8. Total Annual Recreational Value to Visitors to Eight East Bay Parks

Park	Crown Memorial State Beach	Hayward Regional Shoreline	MLK, Jr. Shoreline	Oyster Bay Regional Shoreline	Estuary Park	Union Point Park	Marina Park	HARD Nature Center & Trails	Total
Hiking	$0	$0	$0	$504,176	$0	$0	$0	$0	$504,176
Running	$0	$0	$0	$0	$0	$0	$0	$0	$0
Walking	$0	$0	$0	$0	$9,165	$10,693	$397,150	$0	$417,008
Hiking/ Running/Walking	$1,583,519	$171,739	$1,415,591	$0	$0	$0	$0	$5,499	$3,176,347
Beach/ Swimming	$2,804,202	$0	$0	$0	$0	$0	$0	$0	$2,804,202
Visitor Center/ Interpretive	$3,127,071	$0	$0	$0	$0	$4,094	$0	$202,231	$3,333,396
Picnicking	$500,059	$0	$471,864	$252,088	$0	$2,291	$556,010	$0	$1,782,311
Biking	$291,701	$122,670	$629,152	$252,088	$9,165	$0	$397,150	$5,499	$1,707,425
Special Events	$268,035	$0	$252,922	$0	$14,738	$1,228	$0	$0	$536,922
Sports	$125,015	$0	$0	$0	$50,408	$764	$79,430	$0	$255,616
Volunteer Activities	$125,015	$0	$0	$0	$0	$0	$0	$0	$125,015
Dog Walking	$0	$171,739	$0	$0	$0	$0	$0	$0	$171,739
Bird Watching	$0	$24,534	$0	$0	$0	$0	$0	$0	$24,534
Wildlife Watching	$0	$0	$0	$0	$0	$0	$0	$7,332	$7,332
Kayaking/ Canoeing	$0	$0	$1,348,917	$0	$58,950	$0	$0	$0	$1,407,867
Boating	$0	$0	$674,459	$0	$0	$0	$0	$0	$674,459
Playground	$0	$0	$0	$0	$0	$0	$158,860	$0	$158,860
Total Rec Value	$8,824,614	$490,682	$4,792,905	$1,008,352	$142,425	$19,069	$1,588,600	$220,561	$17,087,208

Source: Tables 3 and 4.

Table 9. Annual Revenues and Replacement Value of Structures for Eight East Bay Parks

Park	Annual Revenues	Replacement Value of Structures
Crown Memorial State Beach	$70,000	$9,536,000
Hayward Regional Shoreline	$0	$4,193,000
MLK, Jr. Shoreline	$39,000	$11,086,000
Oyster Bay Regional Shoreline	$0	$845,000
Estuary Park	$10,500	$2,753,277
Union Point Park	$6,000	$2,260,000
Marina Park	NA	NA
HARD Interpretive Center & Trails	$0	$5,000,000

Source: Information provided by BCDC.

Table 10. Present Value Losses Associated with Eight East Bay Parks Presumed Inundated in 2050 or 2100 Due to Sea Level Rise

Park	Present Value of Loss Occurring in 2050	Present Value of Loss Occurring in 2100
Crown Memorial State Park		
Annual Recreational Value	$92,175,184	$18,330,880
Annual Revenues	$0	$0
Replacement Value of Structures	$3,011,026	$686,836
Total present value of loss	$95,186,210	$19,017,716
Hayward Regional Shoreline		
Annual Recreational Value	$5,125,288	$1,019,266
Annual Revenues	$0	$0
Replacement Value of Structures	$1,323,955	$302,003
Total present value of loss	$6,449,243	$1,321,270
MLK, Jr. Shoreline		
Annual Recreational Value	$50,063,022	$9,956,034
Annual Revenues	$0	$0
Replacement Value of Structures	$3,500,444	$798,476
Total present value of loss	$53,563,466	$10,754,510
Oyster Bay Regional Shoreline		
Annual Recreational Value	$10,532,471	$2,094,593
Annual Revenues	$0	$0
Replacement Value of Structures	$266,812	$60,862
Total present value of loss	$10,799,283	$2,155,454
Estuary Park		
Annual Recreational Value	$1,487,663	$295,852
Annual Revenues	$0	$0
Replacement Value of Structures	$869,357	$198,307
Total present value of loss	$2,357,020	$494,158
Union Point Park		
Annual Recreational Value	$199,184	$39,612
Annual Revenues	$0	$0
Replacement Value of Structures	$713,603	$162,778
Total present value of loss	$912,787	$202,390
Marina Park		
Annual Recreational Value	$16,593,303	$3,299,910
Annual Revenues	$0	$0
Replacement Value of Structures	$0	$0
Total present value of loss	$16,593,303	$3,299,910
HARD Nature Center & Trails		
Annual Recreational Value	$2,303,814	$458,160
Annual Revenues	$0	$0
Replacement Value of Structures	$1,578,768	$360,128
Total present value of loss	$3,882,582	$818,288
All Parks		
Annual Recreational Value	$178,479,930	$35,494,306
Annual Revenues	$0	$0
Replacement Value of Structures	$11,263,964	$2,569,390
Total present value of loss	$189,743,893	$38,063,696

Source: ERG estimates and previous tables.