FINAL

Port of San Francisco Waterfront Resilience Program

Multi-Hazard Risk Assessment Northern Waterfront and Embarcadero Seawall Summary Report

August 2020

Prepared for

Port of San Francisco

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Contents

Tables

Figures

Glossary

Term	Definition
100-year flood (1-percent-annual-chance flood)	A flood event having a 1 percent chance of being equaled or exceeded in any given year.
500-year flood (0.2 -percent-annual-chance flood)	A flood event having a 0.2 percent chance of being equaled or exceeded in any given year.
adaptation	Adjustment in natural or human systems in response to an actual or expected climatic stimulus.
astronomical tide	Tidal water levels that fluctuate only because of gravitational influences (because of the moon/sun and the earth's rotation), not atmospheric influences. Astronomical tide levels do not include any increases in water level because of storm surge (from wind or changes in atmospheric pressure) or influences from riverine discharges.
climate adaptation	Adjustment or preparation of natural, built, or social systems to new or changing climate conditions and climate variability that moderate harm or exploit beneficial opportunities.
climate change	A change in global or regional climate patterns, in particular a change apparent from the mid to late 20th century onward and attributed largely to the increased levels of atmospheric carbon dioxide produced by the use of fossil fuels.
climate change impacts	The impacts of climate variability and extreme events on built, natural, and human systems. Potential impacts are assessed in the absence of potential adaptation measures.
consequences	The extent to which people or assets can be affected by a hazard exposure. Consequences are the product of exposure and vulnerability. Consequences are qualitative and quantitative impacts to exposed and vulnerable people, buildings, or infrastructure, and many can be communicated in terms of economic losses.
criteria	Definitions used to map indicators to a qualitative rating scale for sensitivity and adaptive capacity.
datum	A set of points of reference from which measurements can be made.
design life	Period of time during which an asset is expected by its designers to operate or function within its specified parameters.
economic vulnerability	Economic variables that may be affected by climate impacts such infrastructure damage, repair or replacement costs, and lost revenues during periods of recovery.
Embarcadero Seawall Program area	Includes the flood hazard area, seismic hazard area, and Port property along the extent of San Francisco's northern seawall (Hyde Street Harbor to Oracle Park).

Term	Definition
Embarcadero Seawall Program Port facilities	Spatial units of the Port’s property, modified from the Port’s internal facility code boundaries.
environmental vulnerability	Environmental variables that may be affected by climate impacts such as species biodiversity, water quality, and ecosystem functions.
exposure	People, buildings, infrastructure systems, and other resources (assets) within areas most likely to experience hazard impacts. For the Embarcadero Seawall Program, exposure analysis to flood and seismic hazards is limited to buildings, infrastructure systems, and assets associated with, and in the vicinity of, the seawall. Nevertheless, exposure does not indicate vulnerability, or the extent or severity of consequences such as whether people, buildings, or infrastructure will experience impacts or loss.
flood	Normally dry land becoming temporarily covered in water.
hazards	The events and resulting effects that affect society. This project is focused on the natural hazards associated with seismic and flood scenarios. Seismic hazards include effects such as ground shaking, liquefaction, and lateral spreading. Flood hazards are associated with inundation due to sea-level rise, waves, and storm surge.
inundation	The process of dry land becoming permanently submerged.
king tide	While the term ”king tide” isn’t a scientific term, it is used to describe an especially high-tide event when there is an alignment of the gravitational pull between sun and moon.
mitigation	The lessening of the adverse impacts of hazards and related disasters.
non-Port property	Land not under Port jurisdiction that falls within the Embarcadero Seawall Program area, unless specified otherwise.
Port assets	Buildings and marine structures on Port property.
Port property	Land under Port jurisdiction that falls within the Embarcadero Seawall Program area, unless specified otherwise.
resilience	The capacity of a system and its component parts to cope with hazardous shocks and stresses in a timely and efficient manner by responding, adapting, and transforming in ways that restore, maintain, and even improve its essential functions, structures, and identity while retaining the capacity for growth and change.
risk	Commonly considered to be the combination of the likelihood of an event and its consequences.
scenario	A plausible description of a possible future state used for planning. A climate change scenario describes the difference between a future climate scenario and the current climate.

Term	Definition
sensitivity	Characteristics of assets or asset systems that could lead to damage or disruption in the event of temporary flooding or permanent inundation. For example, electronic equipment is sensitive to flooding and it is more likely to be destroyed by a short-term flood event than a paved roadway that is less sensitive and may recover quickly once floodwater recedes.
storm surge	The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The height of a storm surge event is the difference between the observed sea level and the sea level that is expected based on regular tidal variations.
storm tide	The combination of a storm surge height and the astronomical tide.
useful life	The period of time during which an asset is expected to operate or function.
vulnerability	The extent to which an asset or system is susceptible to harm from an impact.

Acronyms and Abbreviations

AWSS	Auxiliary Water Supply System
BART	Bay Area Rapid Transit
Bay	San Francisco Bay
City	City and County of San Francisco
M	magnitude
MHHW	mean higher high water
MHRA	multi-hazard risk assessment
Muni	San Francisco Municipal Railway
NAVD88	North American Vertical Datum of 1988
OPC	California Ocean Protection Council
PG&E	Pacific Gas & Electric
Port	Port of San Francisco
SFMTA	San Francisco Municipal Transportation Agency
SFPUC	San Francisco Public Utilities Commission
SPRP	Seismic Peer Review Panel
SWEL	stillwater elevation
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

1 Introduction

This report presents a summary of the earthquake and coastal flood risk assessment of the Port of San Francisco's (Port's) northern waterfront, a dense and historic bayfront stretching 3.5 miles from Hyde Street Pier to the 3rd Street Bridge on Mission Creek and home to the Embarcadero seawall (Embarcadero Seawall Program area). This multi-hazard risk assessment (MHRA) supports the Port's Embarcadero Seawall Program, which includes investment of the voter-approved Seawall Bonds (Proposition A). It also supports the development of the Port's overall Waterfront Resilience Program including the U.S. Army Corps of Engineers (USACE) San Francisco Waterfront Flood Resilience Study, which includes all of the Port's land, assets, and functions. This assessment characterizes the existing earthquake and flood risks along this stretch of waterfront including earthquake risk to Port facilities and the Embarcadero corridor, and coastal flood risk to Port, City and County of San Francisco (City), and private facilities threatened by increasing sea-level rise. The MHRA findings will be used to help guide investment decisions to enhance the vibrancy and resilience of this important section of waterfront. Figure 1-1 shows the entire Port jurisdiction and denotes both the Embarcadero Seawall Program area, addressed in this document and the USACE study area as well as the neighborhoods within and adjacent to the waterfront.

1.1 Background and Purpose

The Port is responsible for 7.5 miles of San Francisco waterfront, from Hyde Street Pier in the north to India Basin in the south. The Port holds this land in public trust for the use and enjoyment of the people of California, and develops, markets, leases, administers, manages, and maintains over 1,000 acres of land. This land adjacent to San Francisco Bay (Bay) includes some of the region's most popular open spaces and attractions, two national historic districts, hundreds of small businesses, nearby housing, and maritime and industrial uses. The Port's jurisdiction also includes important regional and citywide assets, including transportation networks like Bay Area Rapid Transit (BART) and San Francisco Municipal Railway (Muni); critical utilities, including drinking water and wastewater; key disaster response facilities and state and regional maritime assets and functions.

The Port has developed a Waterfront Resilience Program to address immediate hazards, including earthquakes and flooding, as well as longer-term hazards such as sea-level rise. The Port's Waterfront Resilience Program efforts are intended to ensure that the waterfront and its important regional and citywide assets are resilient in the face of hazards such as earthquakes and coastal flooding, which continues to increase due to sea-level rise. As part of the Waterfront Resilience Program, the Port is leading the Embarcadero Seawall Program, a citywide effort to create a more sustainable and resilient waterfront and the USACE Flood Resiliency Study. The Embarcadero Seawall Program was developed to address current, urgent earthquake and flood risks, and plan ahead for future risks associated with sea-level rise from Fisherman's Wharf to Mission Creek (the Embarcadero Seawall Program area). The USACE Flood Resiliency Study is a partnership between the Port and USACE to study the flood risks and consequences to the San Francisco waterfront from Aquatic Park to Heron's Head Park.

To fully understand the current and future risks and inform investments to reduce those risks, the Port has undertaken a comprehensive MHRA. The MHRA investigates a range of both earthquake and flood hazard scenarios and evaluates how those scenarios might cause damage and disrupt the transportation and utility infrastructure, buildings, and marine structures along the waterfront and affect the lives of the people who live, work, and recreate along the waterfront and shoreline.

Additionally, the MHRA evaluates the consequences and risks to the waterfront critical functions, including maritime activities, historic resources, public realm, jobs and small businesses, disaster response, and environmental resources. The detailed MHRA analysis and findings are documented in multiple individual reports.

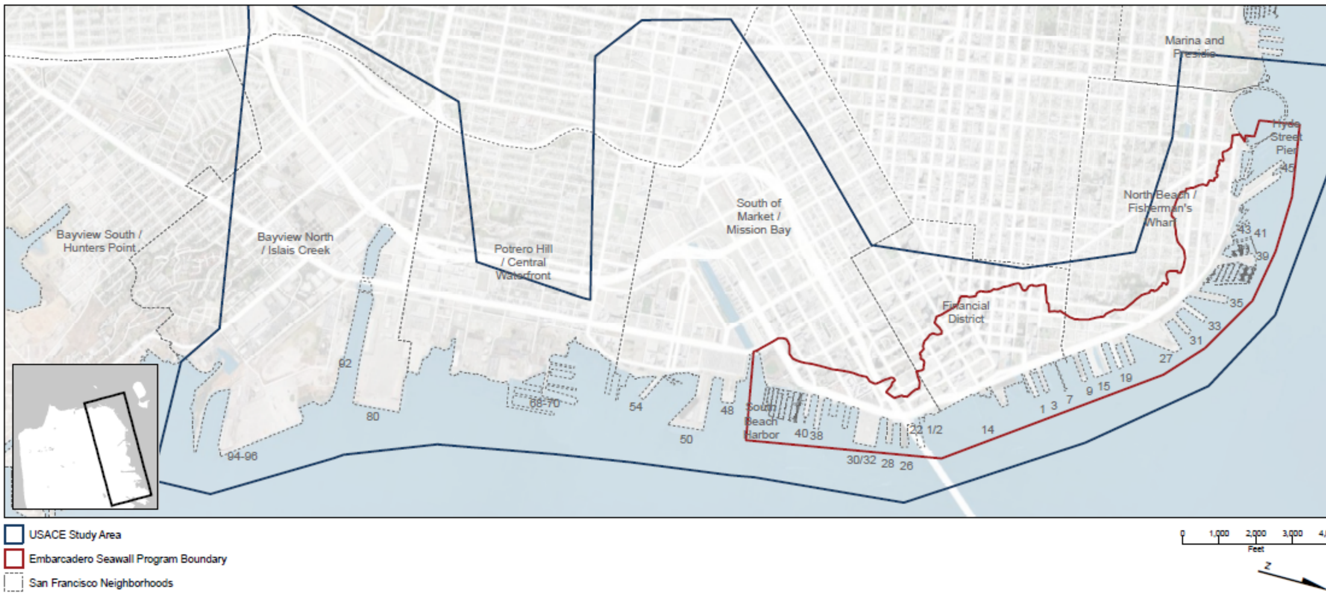


Figure 1-1. Embarcadero Seawall Program Boundary and USACE Study Area

Note: Data and map were developed specifically for the Port of San Francisco planning level program-wide assessment and should not be interpreted as site-specific assessment.

Basemap Source: Mapbox, OpenStreetMap

Figure 1-2 presents the individual reports contributing to the full MHRA, their relationship to one another, and their role as the building blocks of this risk assessment.

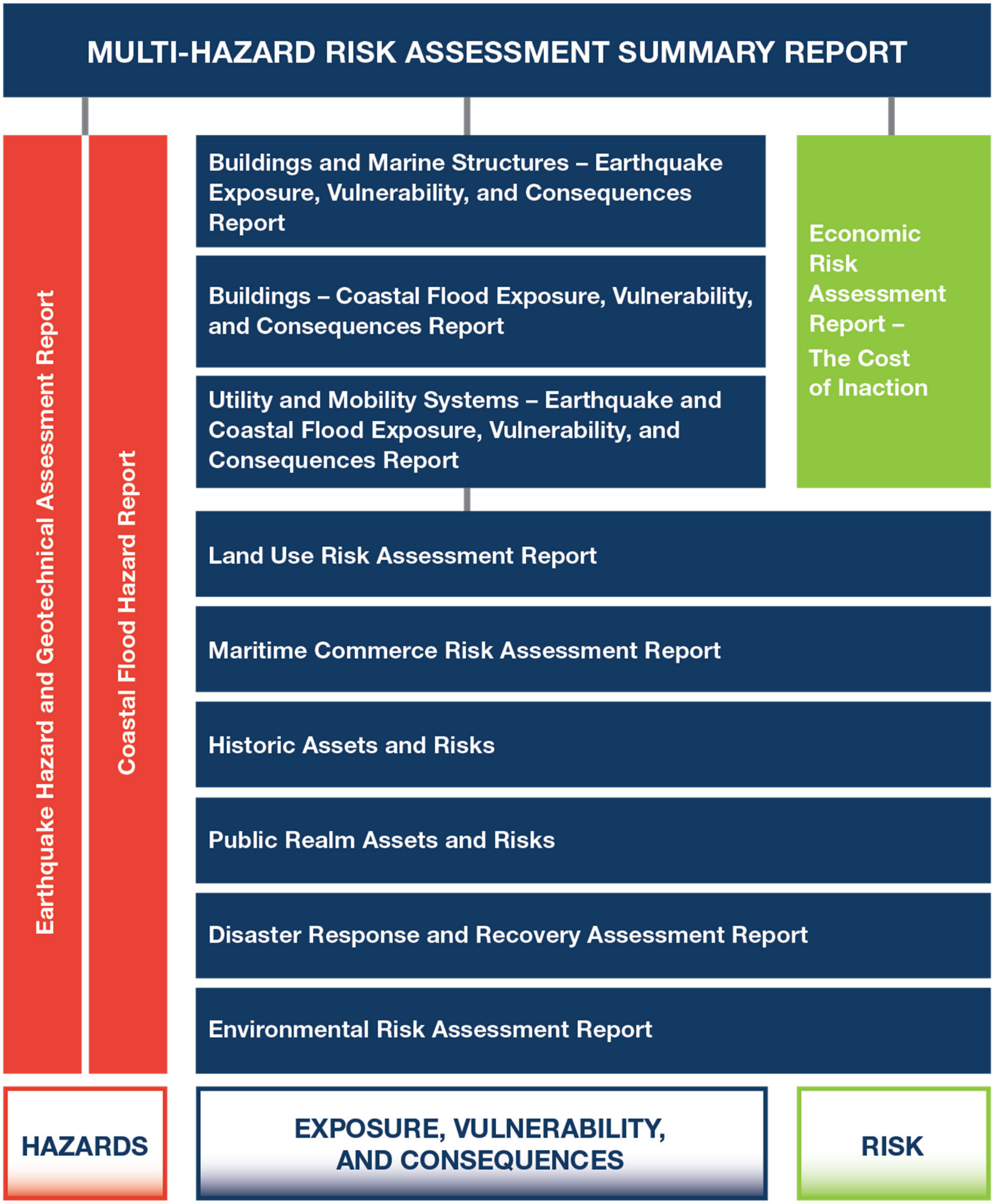


Figure 1-2. Multi-hazard Risk Assessment Key Building Blocks and Contributing Reports

The key buildings blocks for the MHRA are defined as follows:

- **Define Hazards**: Hazards are events with the potential to impact society and the environment. The Waterfront Resilience Program focuses on the two hazards with the highest consequences for the San Francisco waterfront and shoreline: earthquakes and flooding. The MHRA is focused on earthquake and coastal flood hazards that could impact the Embarcadero Seawall Program area. Seismic hazards include effects such as ground shaking and permanent ground displacement resulting from either liquefaction or lateral spreading. Coastal flood hazards captured in this assessment are associated with inundation due to waves, storm surge, atmospheric effects (for example, El Niño), extreme storms, and sea-level rise. Hazard relationships developed for risk assessment include the intensity and likelihood of occurrence. For both seismic and flooding, the MHRA considers a range of hazard scenarios.

- **Identify Exposure of Assets and Functions**: Exposure refers to the people, buildings, infrastructure systems, and other resources (assets) within the Embarcadero Seawall Program area that may intersect with the defined hazards. For the MHRA, exposure analysis is limited to buildings, infrastructure systems, people using the waterfront, and assets within the hazard zones for seismic and flood risks associated with the Embarcadero seawall. For this analysis, seismic exposure is limited to the influence zone of the seawall only. Coastal flooding exposure includes the extent of projected inland flooding and thus incorporates a larger area. Exposure does not indicate vulnerability, and it does not define the extent or severity of consequences such as whether people, buildings, or infrastructure will experience impacts or loss.

- **Characterize Vulnerability**: Vulnerability refers to the extent to which people, buildings, infrastructure assets, or systems are susceptible to harm from the intensity of a range of hazard scenarios. Simple exposure does not indicate vulnerability, as individual assets have different capacity to withstand the effects of the range of hazard scenarios.

- **Identify Consequences**: Consequence is the intersection of hazard, exposure, and vulnerability in which the impacts to people, buildings, infrastructure, systems, services, and functions are characterized. Consequences are expressed in the MHRA in both quantitative terms such as physical damage, direct and indirect business losses, and casualties, as well as in qualitative terms for certain waterfront functions where impacts are classified relatively using a low, medium, and high scale.

- **Identify Risk**: Risk is the combination of consequences and their likelihood of occurrence. Risk is commonly the metric that provokes action based upon a community or organization's tolerance for potential damage and disruption. High-consequence hazards with little probability of occurrence can result in actions that reduce those consequences to a more tolerable level, while high-frequency, low-consequence events may not result in any actions or focus on low-cost actions.

Figure 1-3 provides an overview of this process.

This report presents a high-level synthesis of the findings from the overall MHRA effort, including key findings from each contributing report. It is important to note that because it is a summary, this report does not include all findings contained in the 12 contributing reports. For example, many reports include risk findings for each of the four earthquake scenarios evaluated and each of the four sea-level rise scenarios. In contrast, often just one scenario is reported on in this report for clarity and brevity. The MHRA contributing reports contain more information about the risks associated with each earthquake and sea-level rise scenario. This report in combination with the contributing reports, will be used to support decision makers in selecting and designing future projects to reduce risks.

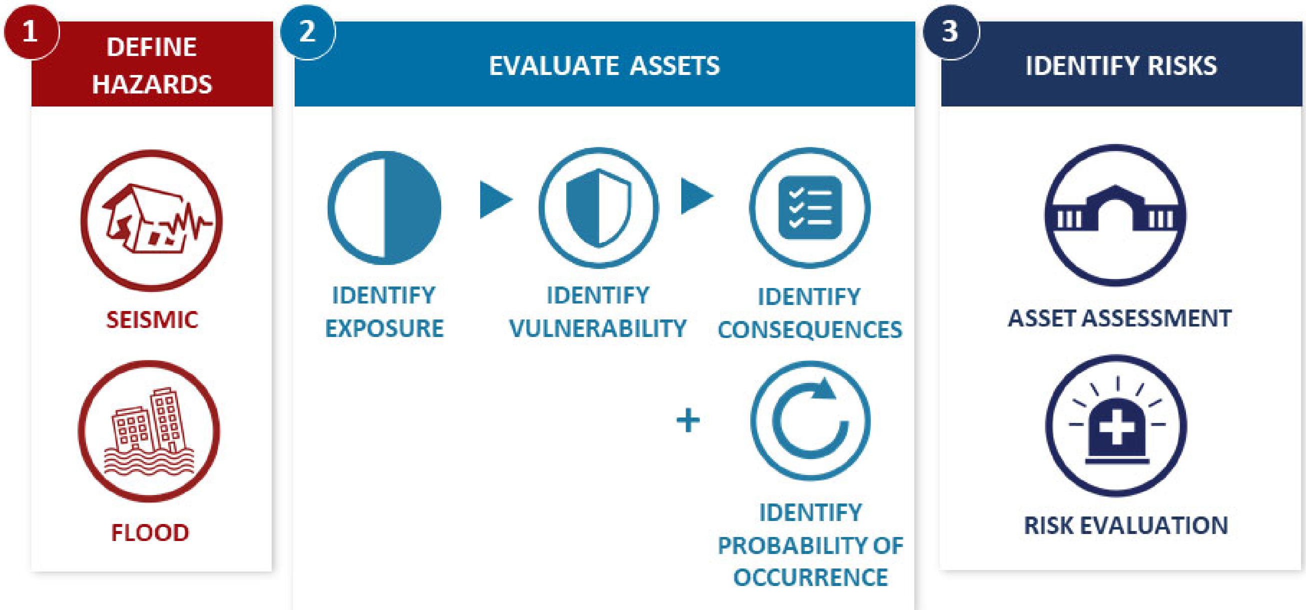


Figure 1-3. Multi-hazard Risk Assessment Process

A Planning-level Study to Support Decision Making

The MHRA represents nearly 3 years' worth of investigation from a broad and dedicated team of Port and industry experts across multiple disciplines. It was an ambitious undertaking, and a clear demonstration of the Port's commitment to understanding the complexity of earthquake and flood risk to support informed resilience efforts moving forward. With this context as a foundation, it is critical to highlight the following:

- **The MHRA is a planning-level study**. Analyses were performed at a variety of levels to produce the appropriate level of understanding for planning purposes program-wide. The analyses draw on and customized industry-respected models and methods where available and applicable, and many industry-respected methods are designed for regional analyses. The level of confidence in results should not be overestimated for individual assets or sites, as this was not the intent of this study.[1] To better understand the performance of a specific building, site-specific analysis is required.
- **The MHRA results are intended to provide guidance for prioritization within the Embarcadero Seawall Program area.** Many assumptions are required to produce results such as those presented in this report and the contributing MHRA reports. These results are useful for capturing the order-of-magnitude of risk, but the relative quantitative results among areas and assets covered in the study are more directly comparable to one another than to results of external studies.
- **Site-specific analyses, pilot projects, and continued stakeholder engagement will be required as the program begins the design phase.** The MHRA provides a broad planning-level foundation for next steps, but there will be many critical discussions, continued engagement with community members and decision makers and the development of a robust and transparent decision-making approach before investment decisions are made and projects are underway.

[1] This is particularly critical with respect to seismic geotechnical, structural, and life safety results. Additional context is available in the *Earthquake Hazard and Geotechnical Assessment Report* (CH2M/Arcadis Team, 2020b) and *Buildings and Marine Structures – Earthquake Exposure, Vulnerability, and Consequences Report* (CH2M/Arcadis Team, 2020a).

This report is organized as follows:

- Overall Takeaways
- Hazards Overview
  - Earthquake Hazard
  - Coastal Flood Hazard
- Findings by Discipline
  - Life Safety
  - Disaster Response and Recovery
  - Maritime Commerce
  - Utilities
  - Transportation
  - Historic Resources
  - Buildings and Marine Structures
  - Environment
  - Open Space and Parks
  - Land Use
  - Cost of Inaction
- Next Steps

1.2 Engagement and Outreach

The Port initiated the Embarcadero Seawall Program and the Waterfront Resilience Program to protect the public. Better understanding of earthquake and flood risk is only important to the extent that it helps the Port understand the consequences of these risks to waterfront stakeholders and the environment.

To that end, since 2017, the Waterfront Resilience Program has connected with tens of thousands of people through robust community engagement efforts to advance work on the Waterfront Resilience Program and its projects, including the Embarcadero Seawall Program and the USACE Flood Resilience Study. This effort included engaging community members, businesses and merchants, advisory committees, non-profit groups and others, and educating them about the aging Embarcadero seawall to ensure that the findings from the MHRA about the hazards, risks, and consequences would be accompanied by an understanding of the priorities, concerns, and issues that mattered to community members and other stakeholders.

The Port's communication and engagement included sharing earthquake and current and future flood risks along the Embarcadero waterfront in the northern waterfront and the current and future flood risk due to sea-level rise as part of the USACE Flood Resilience Study and the Islais Creek Adaptation Study in the central and southern waterfronts. Across all public engagement efforts, the Port presented the same messages:

- Education about the Embarcadero seawall, known risks, and the Port's approach to address those risks
- Education and introduction to the USACE Flood Resilience Study, current and future risks and the assets and services that will be affected if no action is taken
- Introduction to the Waterfront Resilience Program, including life safety and emergency response as the primary program focus

- Introduction to the Port's adaptation planning framework (Strengthen, Adapt, Envision) that will help the Port implement projects over time – a necessity with limited funds and the difference in timing and consequences of the seismic risk (urgent and significant) and flood risk (currently limited to localized flooding and increasing over time as sea level rises)

Community engagement (including community meetings, presentations to groups, tabling at local neighborhood events, and online engagement) also offered the public an opportunity to provide the Port key feedback on program priorities as the Port and its consultants worked with city partners and others to advance the MHRA to better understand the seismic and flood hazards, the assets and services within the program area, and the nature and consequences of the risks.

The stakeholder engagement approach included:

- Community meeting series in three geographies: Embarcadero seawall, Mission Creek/Mission Bay, and Islais Creek/Bayview

- Participation in and hosting of community events like mixers, walking tours, and boat tours throughout the waterfront

- Online engagement through the Waterfront Resilience Program website

- City department engagement

- Presentations to and discussions with advisory committees and boards

1.2.1 Community Meetings

As part of a waterfront-wide outreach effort, the Port has conducted six community meetings since 2018 that focused on the Embarcadero seawall area. Each community meeting was accompanied by a parallel digital engagement activity as described below.

- **Embarcadero Community Meeting #1 (June 2018)**

  - **Introduction:** The project, problems, and Port's adaptation planning framework, and the Embarcadero Seawall Program goals (Act Quickly, Reduce Earthquake Damage, Improve Flood Resilience, Engage the Community, Enhance the City and the Bay and Preserve Historic Resources) were presented.

  - The public was engaged in an "ideation exercise" asking what they want to see along the waterfront in the future. Public feedback included "nature in the city," followed by "getting around," "people places," art, recreation, iconic places, adaptation strategies, and history.

- **Embarcadero Community Meeting #2 (September 2018)**

  - **Assets and Risks:** More detail about the seismic and flood risks associated with the condition of the seawall was presented and the assets and services that rely on the seawall were described.

  - The public was engaged in an exercise asking: What do you love about the waterfront? What do you think is important to the city? What most concerns you if there is a hazard event? Public feedback confirmed the Port's focus on life safety and emergency response.

- **Embarcadero Community Meeting #3 (January 2019)**

- **Goals and Tradeoffs:** The planning framework (Strengthen, Adapt, Envision) and how it will help the Port make strategic decisions over time to increase the resilience of the waterfront was presented. The concept of addressing concerns based on urgency and consequences was introduced. The draft program goals and the Port/USACE Flood Resilience Study were presented.

- The public was led in an exercise to get feedback on the program goals and priorities and tradeoffs in the three planning horizons. Public feedback confirmed the Port's draft goals were appropriate.

- **Embarcadero Community Meeting #4 (June 2019)**

  - **Framework and Vision, Principles, Evaluation Criteria:** An overview of the Waterfront Resilience Program, introduced the MHRA, program vision, principles, and evaluation criteria was p[.

  - The public were engaged in an exercise to provide feedback on the draft vision, principles, and evaluation criteria. Public feedback confirmed the Port's draft principles and draft evaluation criteria were appropriate. Attendees prioritized the Ferry Building and surrounding area as a key asset.

- **Embarcadero Community Meeting #5 (December 2019)**

  - **MHRA Approach and Findings:** The MHRA approach and the progress being made were presented. The use of draft evaluation criteria and the MHRA to guide decision making and make challenging tradeoffs were introduced.

  - Details about findings to date and were shared and the public was asked to offer feedback. Public feedback included many questions and comments across MHRA topic areas.

The presentations and community meeting reports can be found in the Waterfront Resilience Program Library (Waterfront Resilience Program, 2020b).

The community meeting series also included meetings in Mission Creek/Mission Bay and the Islais Creek/Bayview geographies and those meetings follow the same meeting series sequence as the Embarcadero seawall segment. More information on community meetings can be found on the Waterfront Resilience Program Library (Waterfront Resilience Program, 2020b) under the Community Meetings section.

Upcoming community meetings in the series will include presentations and community engagement around MHRA key findings, engagement and outreach key findings, flood and seismic measures, an introduction to alternatives, draft alternatives, Proposition A funded projects, recommendations for next actions (including integrated alternatives for additional areas of the waterfront), additional seismic risk reduction projects, the USACE Flood Resilience Study preferred plan, and the planning processes and future studies to advance more difficult areas.

1.2.2 Digital Engagement

The Waterfront Resilience Program website has provided a number of opportunities for online engagement, as well information related to meetings, findings, explainer videos, walking tours and other engagement opportunities (Waterfront Resilience Program, 2020a). Online engagement has included:

- **Map Your Priorities Along the Waterfront**: this mapping exercise asks the public to inform how projects along the waterfront are prioritized and defined. It is modified from a table-top activity at Embarcadero Community Meeting #2 in September 2018 and two USACE/Port Flood Study Meetings in March 2019.

- **It's Your Turn: Provide Feedback on the Mission Bay/Mission Creek Resilience Goals**: this online engagement provides stakeholders a way to engage and provide input on the draft Mission Bay/Mission

Creek Resilience Goals that were drafted based on input from Mission Bay/Mission Creek Community Meeting #1.

- **It's Your Turn: Provide Feedback on the Waterfront Resilience Program Vision, Principles, and Evaluation Criteria**: provides a way for people visiting the Waterfront Resilience Program website to provide input on the draft program vision, principles, and evaluation criteria in the Embarcadero seawall segment to augment the feedback received in Community Meetings #3 and #4.

- **Think Big and Help the Port Envision the Waterfront in 2100 and Beyond**: this online activity parallels in-person outreach on the Envision effort and asks the public to imagine the waterfront in the year 2100.

1.2.3 In-Person Engagement

Since 2017, the Port has connected with Bay Area families at over 100 in-person events – and counting. Almost all events have been staffed by a multilingual outreach team.

- **I Love the Waterfront:** This outreach activity included over 100 events throughout the city to connect people to the waterfront by asking what they love about the waterfront. These events led to more than 13,500 people contacted, 9,000 pieces of collateral distributed, and 3,500 engagement activity participants. The following are some select responses to the "I love the waterfront" prompt from events:

  – "I like the way the Bay shines in the sun!"
  – "Peace on the water"
  – "The waterfront makes me feel good and alive"
  – "I enjoy walking along the waterfront on the weekends!"
  – "I love seafood and the sea lions!"
  – "Sea animals and the view"
  – "I like walking along the pier and seeing the sights"

- **Envision Engagement**: In 2019, an outreach activity based on the Envision activity from Embarcadero Seawall Community Meetings #1 and #3 at was held at 22 events throughout the city. These events led to almost 4,000 people contacted, 2,500 pieces of collateral distributed, and 2,000 engagement activity participants. After each event, a photo of the map filled with the cards and pulled out themes from the event was taken. Feedback from 2019 Envision outreach includes the following:

  – Connecting the city with the waterfront
  – A natural and environmentally sustainable waterfront
  – Increased transportation options
  – Recreation opportunities
  – A vibrant and exciting waterfront
  – Affordable activities and family-friendly activities
  – Special destinations and big attractions
  – Small things to improve the waterfront

  The input received on Envision in Community Meetings, outreach events, online, and other stakeholder engagements will be used to inform the Envision process of developing three to five concepts of a San Francisco waterfront and shoreline that is resilient to 2100 and beyond. The Envision process will occur during 2020, with draft concepts developed in the late spring and early summer and final concepts developed in late fall and early winter. The concepts will be designed to address a range of sea-level rise projections and achieve other objectives including those shared with the Port at the stakeholder engagement events and meetings.

- **Waterfront Resilience Program Mixers and Pop-Ups:** the Port hosted a series of free "mixers" and pop-up events in Bayview that saw hundreds of attendees, including families, who engaged in outreach activities and shared input on the program.

- **Waterfront Resilience Program Community Partnerships:** the Port connected with key community-based organizations to help connect with communities across San Francisco about the Waterfront Resilience Program. Highlights include partnerships with Cal Academy, WorldWideWomen Girls' Festival, and more.

- **Waterfront Tours:** Walking tours were also used to bring the program into the community and engage and communicate. Activities included a series of walking tours along the Embarcadero seawall and in the Islais Creek area, and a boat tour to see the waterfront from the important perspective of the Bay. The walking tours allowed for the sharing of the seismic and flood risks and highlighted critical assets and services along the shoreline. Highlights the Embarcadero tours included sharing some of the lowest spots along the waterfront, the new Ferry Terminal expansion built to accommodate both seismic and flood risk, and the Pier 14 sea-level rise markers that demonstrate how much elevation change will need to occur to address future flood risk. The Islais Creek tour highlights included all small businesses, critical city and Port assets, critical mobility assets and ecological benefits that exist in Islais Creek despite its industrial nature.

1.2.4 City Department Engagement

City partners were engaged through presentations to the Port Commission, conversations with the Seawall Executive Steering Committee, and a presentation series to City agencies. The focus of these presentations and ensuing discussions included understanding more about priority assets along the waterfront, along with ideas for improving seismic and flood safety, and working closely with teams from the City Planning Department, Office of Resilience and Capital Planning, San Francisco Public Utilities Commission (SFPUC), San Francisco Municipal Transportation Agency (SFMTA), BART, Public Works, Recreation and Parks, and others to better understand potential impacts to infrastructure and assets

Ongoing close coordination with partner agencies on mid- and long-term planning will continue to help inform Proposition A Strengthen Projects and recommendations for projects, planning efforts, and partnerships that will be advanced in the Adapt Plan.

1.2.5 Community Advisory Group Engagement

Events and meetings in existing community spaces provided some of the most engaging interactions. Since 2017, the Port has coordinated over 115 community and stakeholder group presentations in 12 different languages. This includes presentations and discussions with advisory groups and advisory committees. The standard format for this engagement was a 15-minute presentation describing the Waterfront Resilience Program, the hazards and potential risks and consequences relevant to the group, adaptation planning framework, projects within the program, and community engagement approach and opportunities for input. In the past year, the Waterfront Resilience Program was invited to present to and have discussions with the following groups:

- All Port Advisory Committees/Groups on a quarterly basis (sometimes every 4 months)
- Southeast Community Facilities Commission
- Bayview Community Advisory Committee
- Hunter's Point Community Advisory Committee
- Bayview Merchants
- Southeast Facilities and Design Committee

These engagements led to discussions about the Waterfront Resilience Program, projects, and Port and City priorities. The Port continues to collaborate with local advisory groups, including regular presentations and opportunities for input.

1.2.6 Informing Port Resilience Work

The following key messages were heard through this engagement:

- Life safety, emergency response, and critical facilities should be prioritized.
  - Community members consistently prioritize life safety, emergency response, and critical facilities .
  - The Embarcadero promenade and the Ferry Building are two of the most consistently beloved assets along the waterfront.
- Bay ecology, the Bay as an open space, Bay views, and nature and ecology are important to everyone along the waterfront.
- Transportation and utilities are also prioritized by almost everyone.
- Community members consistently stated that the focus of the Waterfront Resilience Program should be on City and Port assets that serve the whole city.
- There is a strong desire for a robust and waterfront-wide pedestrian and bicycle corridor that provides safe and enjoyable access for commuting, recreating, and travelling from the southern waterfront to the northern waterfront, thus providing a unifying corridor for the whole city.
- Jobs and economy are important, and preserving and enhancing job centers such as Fisherman's Wharf, Islais Creek, and the Financial District was important to many,

More specifically, the following input was received on specific aspects of the Waterfront Resilience Program effort:

- **Principles:** community feedback strongly affirmed the Port's focus on life safety and emergency response. Ideas for evolving how to understand and expand what it means to "inspire an adaptable waterfront" included:
  - Connecting the city with the waterfront by providing public space and an accessible waterfront
  - Protecting commercial centers that support jobs
  - Protecting housing, including senior housing
  - Protecting schools and youth facilities
- **Vision and Goals:** community feedback strongly affirmed the Port's draft vision and goals, and the public encouraged the Port to:
  - Continue to be transparent and accountable
  - Continue to engage communities
  - Prioritize life safety and emergency response
  - Prioritize sustainable and nature-based solution where possible
  - Prioritize assets most loved by the community and most important to the city
  - Prioritize projects that use tax dollars effectively and responsibly
- **Evaluation Criteria:** community feedback strongly affirmed the Port's key focus on life safety and disaster response, and putting people first. The assets and services most prioritized were housing, disaster recovery facilities, utilities, and businesses. Community members shared a key focus on protecting transportation assets.

And finally, while community feedback heard over the last 3 years carried many universal themes, there were some specific concerns related to each geography along the waterfront. What follows is what we heard that resonated as distinct feedback for each of the three waterfront geographies:

- **Embarcadero Waterfront**
  - Key community-prioritized assets include: Muni Tunnel, Ferry Building, Exploratorium, and Fisherman's Wharf.
  - Increased transportation options, open space and parks, and more family-friendly activities are wanted.
  - There is a desire.to preserve and enhance jobs and the diversity of jobs along the Embarcadero.
  - The Embarcadero promenade is viewed as a critical asset and there is a strong desire to preserve and enhance it.
- **Mission Creek / Mission Bay Waterfront**
  - Homes, including low-income housing, should be prioritized.
  - Environmental issues were highlighted, including Mission Creek, as an ecological and open space asset.
  - It is vital to reach youth via public engagement efforts.
- **Islais Creek / Bayview Waterfront**
  - Homes, including low-income housing, should be prioritized. Environmental concerns should be prioritized and anti-displacement should be centered in any work.
  - Community members broadly supported the work on the Embarcadero seawall, recognizing the critical nature of the risk and importance to the entire city, including Bayview. However, they also made it clear that they wanted resilience projects in the southern waterfront and that continued engagement with the communities in the southeast is critical to ensuring equitable and sustainable outcomes along the Port's entire 7.5 miles of responsibility.

1.3 Seismic Peer Review Panel

The Port established an independent Seismic Peer Review Panel (SPRP) to oversee the complex technical work of seismic hazard development, building and infrastructure damage and loss predictions, and overall risk characterization, and to ensure it was carried out using sound and defensible engineering methods. This panel met with the Port and consultant team regularly to review the in-progress work, ask questions, and resolve issues during the assessment. The SPRP consists of the following members:

- **Shahriar Vahdani, Ph.D., PE, SPRP Co-chair**
  - Expertise – Geotechnical/earthquake engineering/advanced numerical modeling/foundations
  - Performed ground motion, site response, seismic soil-structure interaction, dynamic slope deformation, and liquefaction-related ground failure studies for major transportation structures including highways and commute rails, dams, tunnels, port facilities, high-rise buildings, bridges, and pipelines
  - Serves on the San Francisco Tall Buildings Study, Project Technical Committee
  - Serves on many Peer Review Panels in San Francisco, often as a chair

- **Steve Dickenson, Ph.D., PE, SPRP Co-chair**
  - Expertise - Geotechnical/seismology/port engineering foundation systems and earth systems
  - Led post-earthquake reconnaissance investigations focused on ports, harbors, coastal infrastructure, and major bridges (for example, 1989 Loma Prieta, 1995 Kobe, 2001 Nisqually, 2007 Kashiwazaki, and 2011 Tohoku earthquakes)
  - Research leader on dynamic site response, liquefaction susceptibility of sand and silt deposits, seismic slope stability, and dynamic soil-foundation-structure interaction
  - Active member in American Society of Civil Engineers Port seismic design committees
- **Professor Thomas Denis O'Rourke, Ph.D., Cornell University**
  - Thomas R. Briggs Professor of Engineering, Cornell University
  - Expertise – leading researcher on earthquake performance of lifelines in U.S.
  - Runs earthquake testing lab at Cornell University for pipeline development
  - Member, U.S. National Academy of Engineering
  - Former President of Earthquake Engineering Research Institute
- **Professor Jonathan D. Bray, Ph.D., PE, University of California Berkeley**
  - Faculty Chair in Earthquake Engineering Excellence
  - Expertise – seismic performance of earth structures, seismic site response, liquefaction and ground failure and its effects on structures, earthquake fault rupture propagation, and post-event reconnaissance
  - Member U.S. National Academy of Engineering
  - Authored more than 350 research publications
  - Active in University of California seismic program
  - Formerly worked for USACE
- **Mark Salmon, SE**
  - Expertise – structural engineering, earthquake engineering, risk assessment, design and assessment of major civil works
  - BART Earthquake Safety Program, lead engineer
  - Engineer of record for many complex infrastructure projects
- **Daryl English, SE**
  - Expertise – Marine structural engineering, earthquake engineering, design and assessment of marine structures
  - Engineer of record for many significant marine structures

2 Overall Takeaways

The MHRA is an extensive assessment of earthquake and coastal flood risks along the waterfront. This analysis has shown that risk varies significantly along the waterfront and the findings will be used to inform the design of strategies to reduce this risk. Section 4 provides additional high-level findings per discipline, but the following key takeaways stand out:

- **The aging and vibrant Embarcadero waterfront presents a complex problem for seismic and flood resilience improvements that are needed to lower the risk for both the Port and City.**
- **The Port's aging seawall is not the only source of earthquake risk.** Weak soil behind and under the seawall and the interaction between the seawall and adjacent historic pile-supported structures contribute to earthquake risk. With strong ground-shaking, weak soil under the Embarcadero will settle and cause extensive damage regardless of whether the seawall moves toward the Bay.
- **Up to 40,000 people could be at risk on Port property if an earthquake occurs during the day.** The Agriculture Building, timber pile-supported buildings in Fisherman's Wharf, and historic wharves connected to the seawall in the Embarcadero Historic District have high occupancy combined with higher collapse risk.
- **The Ferry Building area is one of the highest risk areas on the waterfront.** A large earthquake will cause significant settlement and lateral spreading in this area, threatening life safety and disaster response efforts as well as many of the day-to-day functions along the waterfront. The Ferry Building itself requires further seismic analysis to understand its likely earthquake performance. This area is the lowest point along the Embarcadero, making it the first section to be impacted by coastal flooding, with king tides already causing some overtopping. The Ferry Building itself is at the edge of the current 100-year flood zone. The Port's public outreach confirmed that stakeholders love this area and recognize the concentration of transportation modes and the area's historic significance.
- **The Embarcadero roadway has significant seismic risk, which could impact disaster response and local and regional transportation.** Due to the presence of weak soil, the Embarcadero transportation and utility corridor is at significant seismic risk. In a 1906-size earthquake, damage to the seawall and Embarcadero may be severe enough to significantly hamper disaster response efforts along the waterfront. A more likely earthquake like the 1989 Loma Prieta earthquake – but centered close to San Francisco – is expected to lead to loss of the Embarcadero as a transportation route for up to 1 year.
- **Older, timber-pile-supported structures in Fisherman's Wharf are at high risk.** These older, pile-supported structures are home to small businesses and workers catering to visitors and residents. These structures are vulnerable to strong ground-shaking and the lateral spreading expected in a moderate to large earthquake.
- **Many historic buildings and bulkhead wharves are at high risk.** The bulkhead wharves are the structures located where the pile supported piers over the Bay meet the land. These structures are interconnected with the seawall and support the ornate, historic bulkhead buildings that line the Embarcadero. These structures are at high risk of earthquake damage and will flood with increasing sea levels.
- **In the South Beach subarea, earthquake instability of the seawall is lower than previously thought**. Lateral spreading and seawall movement is not expected to be a problem in the area, but strong ground shaking is expected to damage wharves and the roadway.
- **The economic consequences of inaction to San Francisco and the wider region are extensive.** Without action, earthquakes will cause loss of life and casualties along the waterfront, diminish the City and Port's

capacity to respond to a disaster, and impact key utility and transportation systems, including the Embarcadero roadway. Without new flood protection, coastal flooding of the Embarcadero through low points on the shoreline will cause significant damage by 2050 and steadily increasing risk of catastrophic flooding to the Embarcadero Muni Tunnel with potential system-wide impacts to BART and Muni.

  - Combined earthquake and flood impacts at the Embarcadero waterfront are expected to cause **as much as $30 billion of economic losses due to damage and disruption by 2100**.

    - Port- and Embarcadero-related earthquake losses are a near-term problem with $0.9 billion in losses estimated by 2050 and $1.5 billion estimated by 2100.

    - Flood losses are an emerging problem that increases significantly as sea-level rise begins to overtop the seawall. Based on the State of California's most likely and high sea-level rise projections, coastal flood losses are expected to range between $4.5 billion and $29 billion on average by 2100. The Embarcadero will experience frequent, disruptive flood impacts several decades before the Port's piers experience flood damages, which are on average 2 feet higher than the roadway.

- **There is a significant flood risk to the waterfront and inland neighborhoods, including the Northern Waterfront, Financial District, and South Beach.** The seawall and bulkhead wharves currently provide 100-year flood protection for most of the Embarcadero waterfront, with exceptions such as in the Ferry Building area. However, sea-level rise will decrease the level of flood protection this infrastructure provides, causing the Embarcadero and adjacent inland neighborhoods to become increasingly at risk for coastal flooding. San Francisco's hard bayfront edge and relatively flat topography of the filled lands behind the seawall are very sensitive to changes in water level once the seawall and shoreline is overtopped. When the water level is 3 feet higher than the shoreline, the floodplain extends into the Financial District by more than 0.25 mile, affecting neighborhoods, small and large businesses, jobs, utilities, regional and citywide transportation, maritime function, and cultural and historic resources. The sensitivity of San Francisco's bayside shoreline to flood risk thresholds makes it critical that a risk-informed approach is taken to increase flood protection.

  - **Today, the waterfront segment between Pier 7 and Rincon Park falls below the 100-year flood protection standard and as sea level rises, other areas will also fall below this protection standard.**

  - **At approximately 1 foot of sea-level rise, anticipated to occur between 2035 and 2050, the Embarcadero roadway and surrounding buildings near the foot of Market street will be significantly inundated during a 100-year extreme tide, resulting in damages and disruption along with severe impacts to over 1 million trips taken by BART and Muni riders.** Repairs to the transit systems could take months to years to fully repair and replace all damaged components.

  - **At just over 2 feet of sea-level rise, expected to occur between 2050 and 2075, the Embarcadero roadway and promenade will reach a tipping point where the 100-year flood causes widespread overtopping of the shoreline, resulting in significant disruption to multi-modal movement, cutting off landside access to all Port facilities and flooding the Financial District nearly to Beale Street.** Such widespread flooding results in severe disruption and damage to the entire Embarcadero corridor and historic district, along with hundreds of other small businesses, residential and commercial uses, jobs and critical services, impacting not only the City but the greater Bay Area region. Additionally, access to Port infrastructure via the Embarcadero is cut off which is expected to eliminate the ability for the Port to carry out its public trust responsibilities and maintain and operate critical City, State, and Port assets and services.

- The MHRA findings will provide important information to guide alternatives development, decision making and prioritization of projects, funding, and action along the waterfront. In addition to the MHRA, the Waterfront

Resilience Program conducted robust community and stakeholder engagement including a community meeting series, presentations to and discussions with advisory groups and advisory committees, online engagement, and hosting of and participation in community events to ensure broad engagement. The results of this deep engagement provided the Port with an understanding of community priorities, concerns, and input on Waterfront Resilience Program vision, principles, goals, and evaluation criteria. With the MHRA findings and the findings from the community engagement, the Port is able to move forward to develop alternatives that will respond to both risks and community priorities.

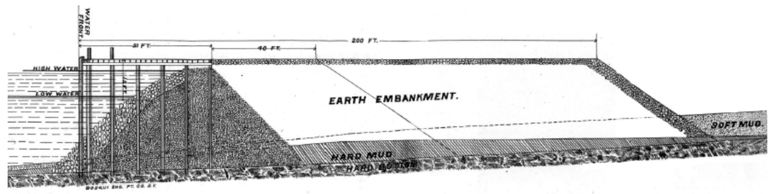
3 Hazards

3.1 Earthquake Hazard

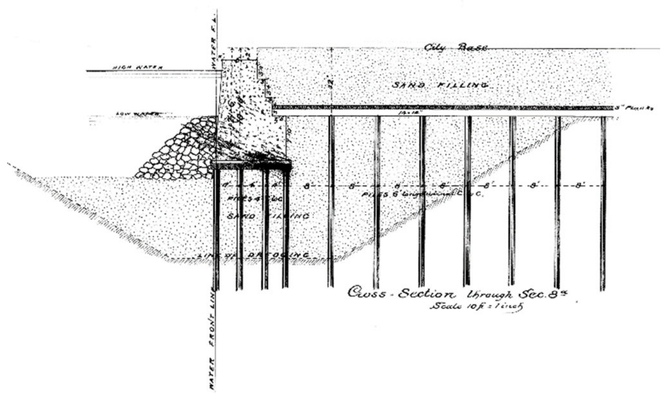
3.1.1 The Seawall and Subsurface Conditions

The entire stretch of Embarcadero waterfront is reclaimed land created over 4 decades starting in 1878 with construction of the first segment of the historic Embarcadero seawall.

The seawall was constructed in 21 primary segments (Figure 3-1) and each construction contract generally consisted of dredging the 100-feet-wide by 30-feet-deep seawall trench, dumping rock to create the dike, driving piles thru the bayside of the dike to support the bulkhead wall and wharf structure, and filling up to 150 feet behind the seawall to create the Embarcadero. Sections 8a and 8b at the Ferry Building are a unique design without a rock dike and consist of a timber-pile-supported concrete bulkhead wall and a landside timber relieving platform to support the weight of the new fill in the very deep bay mud encountered here.



Typical section of the Embarcadero seawall



Section of the seawall at the Ferry Building

Figure 3-1. Seawall Sections and the Historic Shoreline

Basemap source: Satellite imagery

The subsurface is highly varied along the waterfront and a thorough understanding is key to defining the earthquake hazard and developing earthquake and flood improvements. For the MHRA, existing subsurface records were compiled and evaluated, and a new exploration and testing program with 83 borings was implemented to provide high-quality engineering data across the site. Figure 3-2 shows the complexity of ground conditions. In general, there are three main areas with distinct ground conditions:

- Fisherman’s Wharf to Telegraph Hill, which consists of a thin layer of loose sand and Young Bay Mud over denser sand and clays with shallow to moderately deep rock
- The former Yerba Buena Cove centered on Market Street and the Ferry Building, which is characterized by fill over very thick Young Bay Mud with very deep bedrock up to 240 feet below the surface
- South Beach, which is characterized by firmer sand and clays and moderately deep bedrock

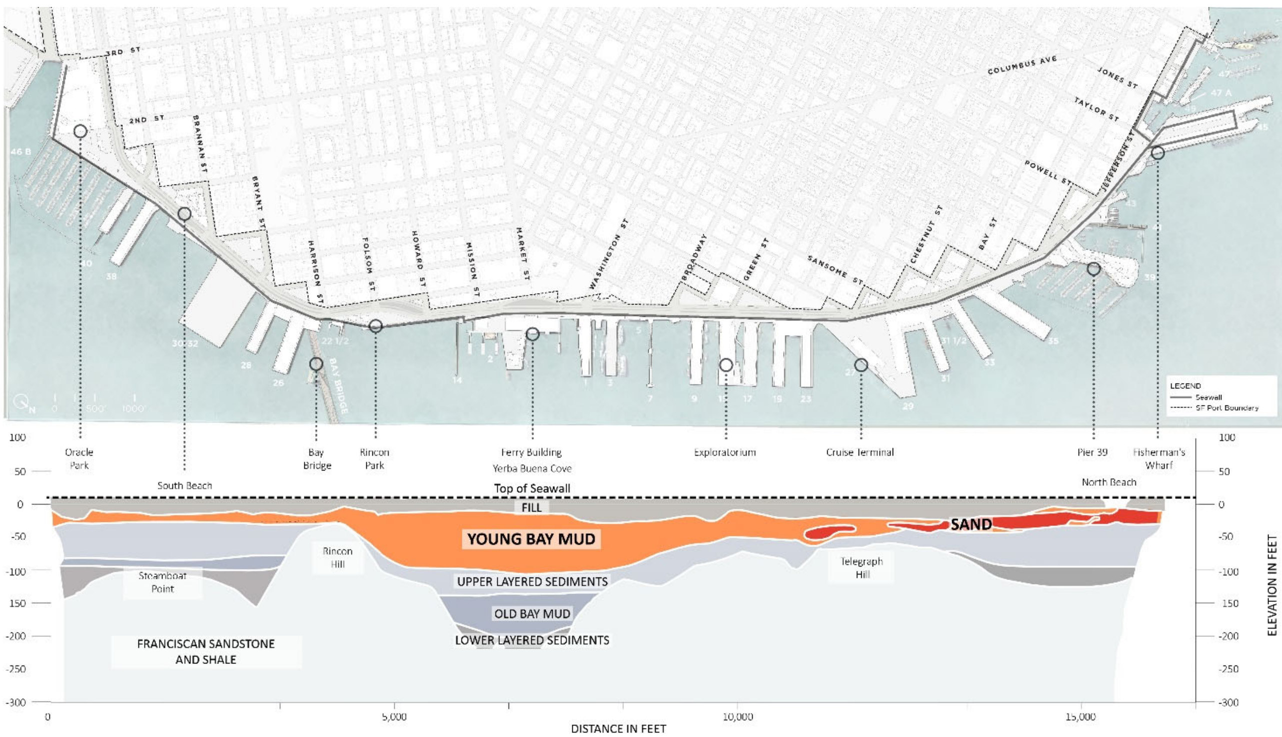


Figure 3-2. Subsurface Conditions along the Seawall

3.1.2 Earthquake Hazard

The Embarcadero seawall is located midway between the San Andreas and the Hayward faults, two active major faults that have produced large earthquakes in the past (Figure 3-3). The northern segment of the San Andreas Fault caused the 1906 magnitude (M) 7.9 (M7.9) Great San Francisco Earthquake centered offshore near the Golden Gate area, the 1989 M6.9 Loma Prieta earthquake centered 60 miles south near Santa Cruz, and is capable of producing an even larger M8 earthquake. The Hayward Fault located across the Bay been silent since the 1868 M6.5 Hayward earthquake, is capable of producing a M7.3 earthquake, and is considered most likely to generate a strong earthquake in the near future (USGS, 2016) (CH2M/Arcadis Team, 2020b). The most current U.S. Geological Survey (USGS) earthquake forecast for the Bay area indicates a 72 percent probability of at least one 6.7M or greater earthquake striking the region before 2043 (Working Group California Earthquake Probabilities, 2014).

The MHRA earthquake risk assessment uses a site-specific probabilistic approach to characterize the earthquake shaking hazard at the waterfront. A probabilistic approach considers how all nearby faults contribute to the likelihood of ground shaking at the site. This differs from a regional assessment that uses specific earthquake scenarios, such as a M7.0 on the Hayward Fault. Four industry standard hazard levels are used in the assessment ranging from frequent shaking similar to the Loma Prieta earthquake (70 percent likelihood in 50 years, or a 43-year return period) to very rare shaking even larger than experienced in during the 1906 earthquake that is used for building codes (5 percent likelihood in 50 years or 975-year return period). These scenarios are further described in Table 3-1.

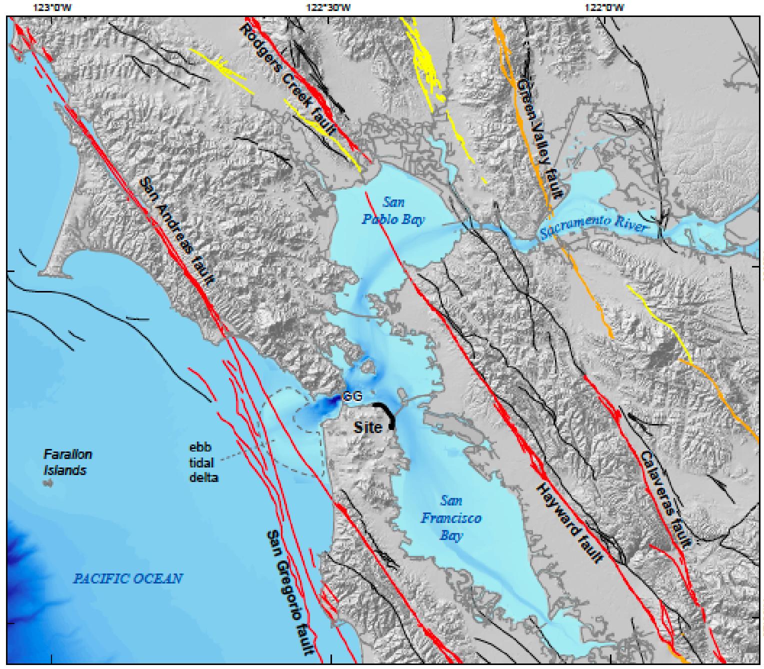


Figure 3-3. Regional Topography and Faults

Basemap source: Topographic and bathymetric data from U.S. Geological Survey

The MHRA assesses the earthquake hazard by:

- Examining the probability of different size earthquakes occurring on each of the nearby faults (USGS models)
- Projecting the ground shaking through bedrock from the fault source to the Embarcadero
- Modifying the shaking based on the characteristics of the Embarcadero soil above bedrock as determined by the exploration program
- Determining related hazards including liquefaction, slope stability, and lateral spreading of the ground using computer models along sections of the waterfront

Table 3-1. Earthquake Scenarios Evaluated in the Multi-hazard Risk Assessment

Likelihood	Earthquake Scenario Return Period and Probability	Historical Context
Frequent	43-year (70% probability in 50 years)	Similar to shaking in San Francisco from 1989 Loma Prieta earthquake (M7+/-)
Occasional	100-year (40% probability in 50 years)	Similar to Loma Prieta earthquake (M7+/-), but with an epicenter located within 10 miles instead of 60 miles away
Rare	225-year (20% probability in 50 years)	Similar, but slightly larger than the 1906 Great San Francisco earthquake, (M7.5+/-) located nearby
Very Rare	975-year (5% probability in 50 years)	M8+ earthquake, larger than 1906 Great San Francisco earthquake, located nearby

The earthquake hazard includes the ground shaking intensity, liquefaction of the soil, and lateral spreading and settlement of the ground due to instability of the seawall. Ground shaking caused collapse of some waterfront pier sheds in 1906 (Figure 3-4). Liquefaction and lateral spreading damaged the Embarcadero in the 1906 (Figure 3-5) and 1989 earthquakes. Figure 3-6 shows differential settlement that occurred along the Embarcadero in 1906.

While this sounds very precise, it is important to keep in mind that earthquake hazard predictions, while improving greatly, are by no means exact science, and that the 1989 Loma Prieta earthquake is the only earthquake where shaking levels were recorded near the waterfront.

Figure 3-4. Damaged Piers after the 1906 Earthquake

Source: Givens, 1906

Figure 3-5. Damage from Lateral Spreading at the Foot of Lombard Street after the 1906 Earthquake

Source: Givens, 1906

Figure 3-6. Differential Settlement on the Embarcadero Near the Intersection of Market Street in 1989

3.1.3 Earthquake Hazard Key Findings

- **Seawall-related lateral displacement hazard is high to very high north of the Bay Bridge and moderate to low south of the Bay Bridge except for a hotspot near Oracle Park**. In the area of the former Yerba Buena Cove, roughly from Rincon Park to Pier 9, the hazard is caused by very thick soft bay mud, up to 100 feet thick, and bedrock more than 240 feet deep. From Pier 9 to Pier 27, the bedrock rises closer to the surface and the bay mud becomes thinner. From Pier 27 to Fisherman's Wharf, the large displacements are primarily a result of shallow liquefiable sand below the rock dike that become more extensive into Fisherman's Wharf. Explorations from Pier 29 to Pier 35 showed less sand below the dike and the displacement hazard is moderate to high as a result (Figure 3-7).

- **The Embarcadero fill liquefaction hazard is very high across the entire waterfront, with some areas starting to liquefy at the 43-year earthquake and nearly all by the 100-year earthquake, with settlements ranging from 0.5 inch to as much as 1 foot and averaging 5 inches overall**. Settlements increase slightly at the 225-year and 975-year earthquakes, indicating behavior much like an on/off switch. This amount of liquefaction will cause significant damages along the Embarcadero at the 100-year earthquake level, especially to brittle infrastructure. Due to high variability in the fill, there is not enough data to reliably predict locations of high and low settlements.

- **Ground shaking affecting Port facilities will be higher than that affecting City buildings on firm soil due to soft soil amplification**. This effect is greatest in the deep mud of the former Yerba Buena Cove area where ground shaking intensity could be more than double that of areas with shallow rock near Telegraph Hill and Rincon Point. More flexible structures, such as the Ferry Building clocktower, may resonate with the soft soil and experience higher levels of shaking than stiff structures.

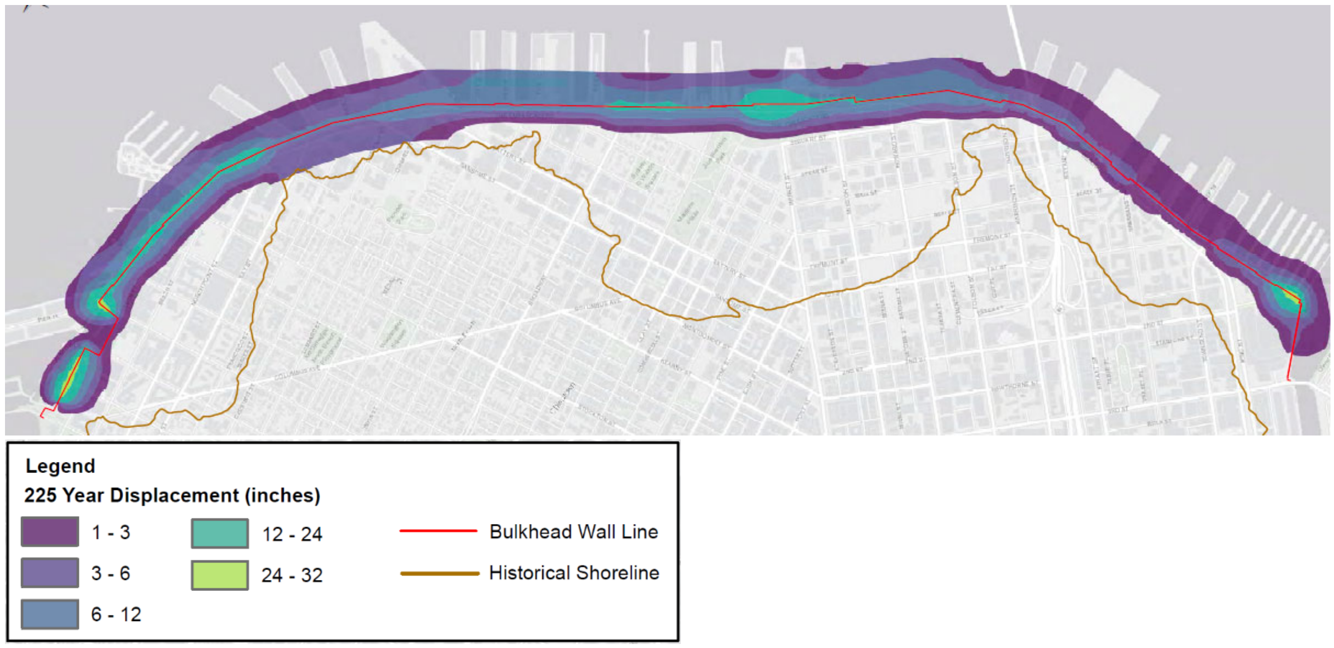


Figure 3-7. Lateral Ground Displacement under the 225-Year Earthquake

3.2 Coastal Flood Hazard

Coastal flooding occurs when the water level in the Bay is greater than the elevation of the piers, wharves, or the seawall along the Embarcadero. The San Francisco waterfront currently experiences localized, minor coastal flooding during yearly king tides, but has not experienced damaging flooding from more extreme tides. However, the likelihood and extent of coastal flooding is expected to increase over time as sea level continues to rise. San Francisco's hard bayfront edge and relatively flat topography near the Bay are very sensitive to changes in water level once the seawall is overtopped.

Previously completed local and regional inundation maps[2] provide valuable insight into flood hazards throughout the Bay, but the MHRA coastal flood hazard and inundation maps are intended to provide additional refinement in the Embarcadero Seawall Program area. This effort incorporates elevation changes associated with recent development, accounts for the influence of wave action on flood depth, and provides direct input to the economic model used to assess the consequence of flooding. It also provides a qualitative evaluation of flood risk to functions serving the city and region.

3.2.1 Water Level Components

Water levels along the waterfront consist of several components as shown on Figure 3-8 and described below.

Daily and Extreme Tides: Visitors to the waterfront can readily observe that water levels fluctuate every day in the Bay. On average, daily tides in the Bay rise and fall as much as 6.5 feet from low to high water due to the gravitational pull of the sun and moon on the oceans.[3] King tides, which can reach 7.5 feet, are extra high

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[2] Includes flood maps from the San Francisco Public Utilities Commission sea-level rise mapping effort, also used for the regional Adapting to Rising Tides Program and *San Francisco Sea-level rise Vulnerability and Consequences Assessment* (City, 2020b). Additional detail regarding the development of the regional flood data is available in the *Climate Stressors and Impacts: Bayside Sea-level rise Mapping Final Technical Memorandum* (SFPUC SSIP, 2015) and the *Sea-level rise Inundation Mapping Technical Memorandum* (AECOM, 2016).

[3] Mean higher high water (MHHW) is a common technical term representing the average daily high water level. MHHW at the Ferry Building is currently considered to be 6.3 feet above North American Vertical Datum of 1988 (1983 – 2001 tidal epoch), and the corresponding value for the low tide (mean lower low water) is -0.2 foot below the same datum (giving a tidal range of 6.5 feet).

astronomical tides that occur yearly when the earth is closest to the sun. Beyond daily and king tide events, temporary highwater levels can be caused by phenomena such as a storm surge, an El Niño event,[4] the Pacific Decadal Oscillation,[5] fresh water inflows, and several other atmospheric processes. Each component can last for different lengths of time and vary in magnitude. The combination of the astronomical tides and these temporary phenomena are often referred to as extreme tides. The likelihood of these extreme tides occurring can be predicted by analyzing the historic water level record to determine how often these events have occurred over the last century. Often, the likelihood of these extreme tides is simply represented as a return period, or how often one would statistically expect to have this water level. The 100-year extreme tide, or 100-year flood, has a 1 percent chance of occurring in any given year. This extreme event is the typical example of a major flood used by the Federal Emergency Management Association to designate areas prone to flood risk, thus requiring higher building and insurance standards. Along the seawall, the 100-year extreme tide is approximately 2 feet higher than a more frequent event expected to occur every year.

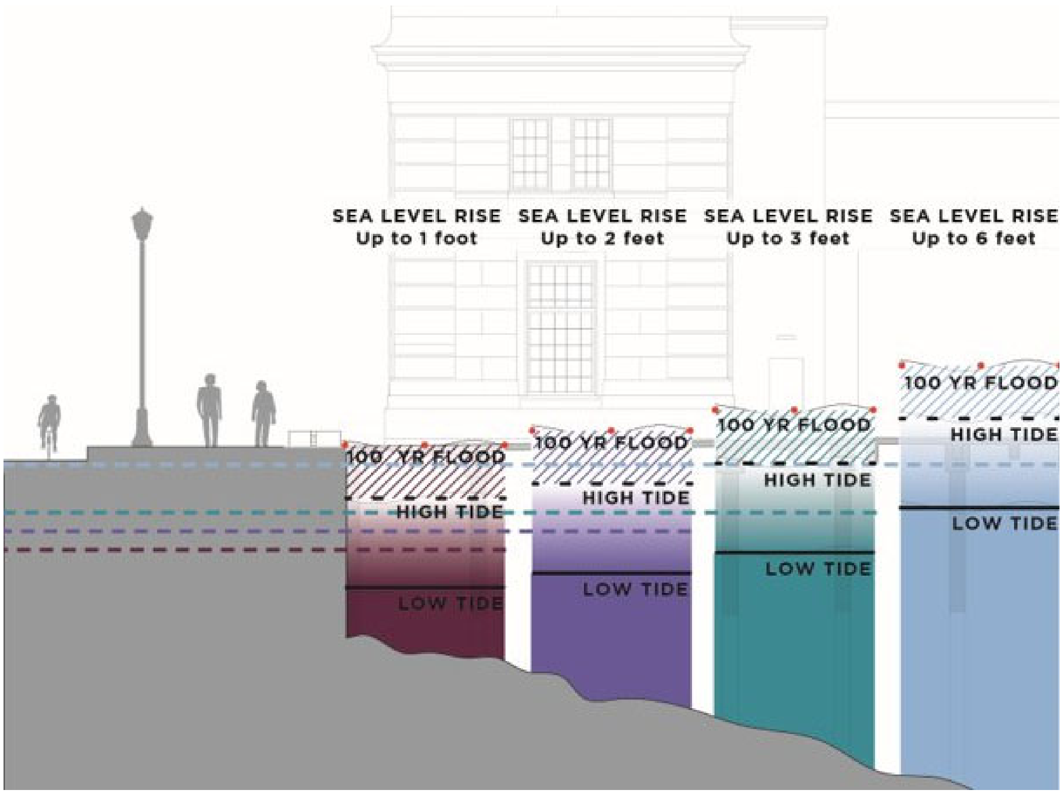


Figure 3-8. Components of Water Levels

Source: CH2M/Arcadis Team, 2019

Waves: Another key component to water level is the influence of waves on the coastal flood hazard. Strong winds gusting across the Bay push water in the form of wind waves toward the seawall, causing overtopping of the hardened shoreline edge. Because the combination of extreme winds and extreme tides is rare, the MHRA used

[4] El Niño is a complex weather pattern resulting from differences in Pacific Ocean temperatures near the equator. An El Niño event or episode typically lasts 9 to 12 months, and prolonged events could last for years. El Niño is considered the "warm phase" of the El Niño-Southern Oscillation cycle, whereas its counterpart La Niña is the “cold phase” of the cycle. In California, El Niño has been associated with larger stormer events.

[5] Pacific Decadal Oscillation is a complex weather pattern resulting from differences in Pacific Ocean temperatures, primarily in the northeast and tropical waters. While the El Niño Southern Oscillation cycle is on roughly an annual timescale, the Pacific Decadal Oscillation changes phase on a longer timescale, on the order of decades or even up to 30 years.

extreme tide water levels with regularly occurring wind waves to keep the likelihood of occurrence consistent, which resulted in smaller wind waves but higher water levels for the assessment.

Sea-level Rise: There are many different sources for sea-level rise projections and guidance, which are periodically revised as the scientific community learns more about the processes driving this global challenge. These projections help asset owners and managers understand when water levels are likely to cause flooding. The City recently updated the *Guidance for Incorporating Sea-level rise Into Capital Planning* (City, 2020a) adopting sea-level rise scenarios from the *State of California Sea-level rise Guidance* published by the California Ocean Protection Council (OPC) (OPC, 2018).

The MHRA flood hazard assessment is designed to evaluate the flood risk for the two scenarios presented in the City guidance, the “Likely” and “1:200 Chance” scenarios assuming a high-emission condition. The “Likely” scenario, estimated to have a 66 percent chance of occurring, will add an additional 3.4 feet to all tides (daily and extreme) in the year 2100. This scenario is intended to be used for planning low-risk projects that are tolerant or easily adaptable to future flooding. Alternatively, the “1:200 Chance” scenario is intended to be used for planning medium- to high-risk projects with little tolerance, or difficulty adapting to future flooding. The “1:200 Chance” scenario will add an additional 6.9 feet to all tides in the year 2100 but has only a 0.5 percent chance of occurring. Figure 3-9 presents a selection of sea-level rise projections provided by OPC (OPC, 2018) and adopted by the City along with three curves used by USACE (USACE, 2018) in evaluation and design of federally funded coastal storm risk management projects, such as the USACE Flood Resiliency Study. The USACE curves are shown for reference only and have not been used in quantification of flood damages through the MHRA.

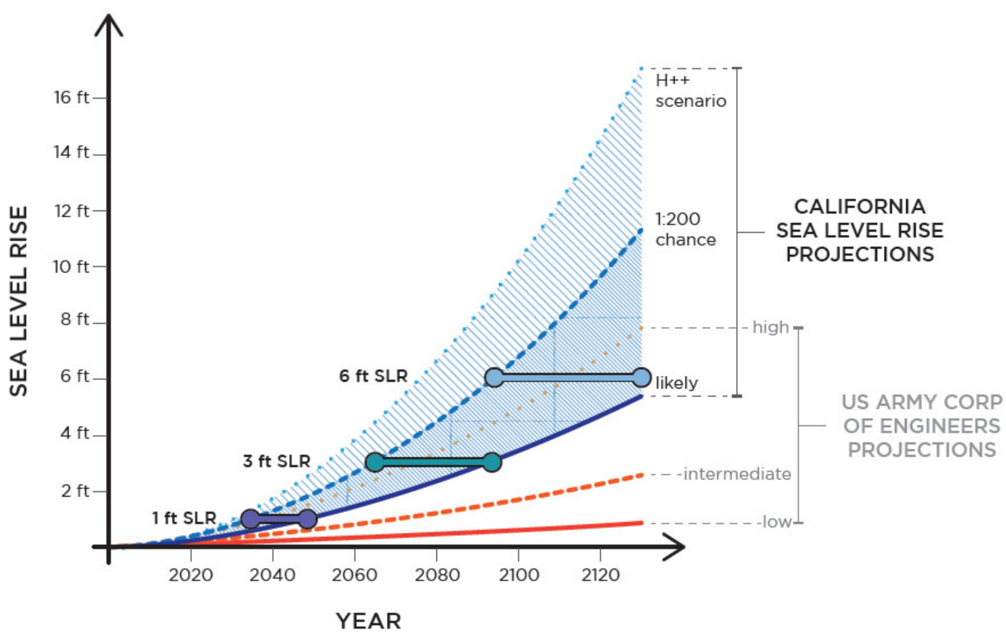


Figure 3-9. Sea-level rise Projections

Image provided for reference, may not reflect the sea level increments and projections of the MHRA analysis.

Source: CH2M/Arcadis Team, 2019

3.2.2 Flood Hazard

In evaluating flood risk, there are many different combinations of sea-level rise and extreme tides that can result in the same water level. Therefore, the MHRA coastal flood hazard assessment employed the “One Map, Many Futures” framework aligned with the Adapting to Rising Tides program developed by the San Francisco Bay Conservation and Development Commission (BCDC, 2020). Each flood map illustrates a water level that represents a range of possible combinations of temporary, event-driven conditions and/or frequently occurring tidal flooding as a result of rising sea levels.

Table 3-2 presents a sampling of water levels based on the likelihood of different extreme tides in combination with specific increments of sea-level rise. An interval of 1.1 feet for sea-level rise is used to align with the difference in elevation between the current 500-year, 100-year, and 10-year storms to maximize utility of the “One Map, Many Futures” approach. All mapped water levels are compatible with City and state guidance and enable the team to capture key tipping points along the waterfront. Following a risk-informed approach, the consequences of flooding are evaluated for the full suite of extreme tides from 1-year to 500-year, to weigh the likelihood of occurrence against the resulting damage and disruption. The MHRA is not intended to establish a flood protection policy, but rather quantitatively and qualitatively measure risk based on projections of sea-level rise combined with varying levels of extreme tides.

Table 3-2. Embarcadero Seawall Program Representative Flood Elevations and Frequencies

Return Period	Description of Likelihood	Water Level above NAVD88 – a national datum established for surveying					
		Current conditions	1.1 feet sea-level rise	2.2 feet sea-level rise	3.3 feet sea-level rise	5.3 feet sea-level rise	6.9 feet sea-level rise
500	1 in 500 chance each year	10.7	11.8	12.9	14.2		
100	1 in 100 chance each year	9.6	10.7	11.8	12.9	15.2	16.5
10	1 in 10 chance each year	8.5		10.7	11.8	14.2	15.2
1	Likely each year	7.5			10.7	12.9	14.2
Tidal Datum MHHW	Likely on a daily basis	6.3				11.8	12.9

[a] The flood map corresponding to the 16.5 feet-NAVD88 SWEL was created as part of the flood hazard mapping effort. This water level can be reached by combining the 100-year SWEL with 83 inches (6.9 feet) of sea-level rise, which corresponds to the projected amount of sea-level rise by OPC 1:200 curve in year 2100. In turn, year 2100 is one time horizon recommended for evaluation in the *Guidance for Incorporating Sea-level rise into Capital Planning* for San Francisco (City, 2020a).

Notes:

Water levels provided here are in reference to the NAVD88. They are approximate and based on the nearest representative flood inundation map produced for the MHRA. This table highlights four of the 12 flood inundation maps produced. Colors represent the same approximate flood elevation occurring at different return periods for different sea-level rise scenarios. Current conditions are representative of the 1983-2001 tidal epoch and sea-level rise increments use a base year of 2000. Therefore, it is assumed that sea level has already started rising toward these sea level increments.

MHHW = mean higher high water

NAVD88 = North American Vertical Datum of 1988

SWEL = stillwater elevation

Table 3-2 illustrates how one particular flood inundation map for a water level of 11.8 feet illustrates both a **temporary flood hazard**, such as a 1-in-100 annual chance flood with 1.1 feet of sea-level rise, or a **permanent flood hazard**, such as a daily flood event with 5.3 feet of sea-level rise. Both temporary and permanent flooding can cause significant damage, and both must be considered for adaptation and resilience measures. However, certain industries and functions occurring along the waterfront will have a different tolerance for damage and disruption associated with flooding, therefore, it is important to view the full spectrum of flood frequencies at the various increments of sea-level rise.

In addition to coastal flooding on the surface, sea-level rise will affect the elevation of groundwater within the soil column. Along the waterfront, the groundwater table fluctuates with the tides, but is on average equal to mean sea level, which is midway between high and low tide. With every increment of sea-level rise, it is expected that the groundwater table will rise an equal amount in this area of the city.

The coastal flood hazard associated with tsunami was not explicitly evaluated as part of the MHRA. In review of prior studies and due to the low likelihood of occurrence, such an event is expected to have a negligible influence in evaluation of damages as part of this risk-based assessment. Additionally, the geography of the Bay ensures that much of the tsunami wave energy is dissipated as it passes through the Golden Gate strait, decreasing the expected damage to marine structures and buildings along the Embarcadero waterfront. However, tsunamis may cause damage to floating facilities and berthed vessels, which is not quantified as part of the MHRA.

3.2.3 Assessment Approach

Table 3-3 summarizes the analyses within this assessment.

Table 3-3. Multi-hazard Risk Assessment Coastal Flooding Analyses

Analysis	Description
Stillwater selection	Stillwater inundation maps representing today's water levels were combined with a suite of sea-level rise increments. Each set of maps was reviewed to identify the tipping points ensuring the stillwater levels used in the MHRA had enough data before and after this tipping point to perform the risk analysis. This step also ensured all sea-level rise projections were covered by the range of selected maps.
Wave analysis	For each selected water stillwater level, the historic wind record was used to select a wind speed likely to occur at the same time. For each stillwater level and wind speed, the wave conditions within the Bay were predicted using a SWAN model. Due to localized changes in water depth and structure conditions, a more detailed FUNWAVE model was then used to predict how waves in the Bay (SWAN) interact with the shoreline to produce overtopping and flooding of the piers, wharves, and seawall.
Development of inundation maps	Refined elevation data and results from wave analysis were used to create 12 inundation maps for the northern waterfront. Of these, the eight lower water level maps include the effects of wave action, but the four highest water level maps do not incorporate waves. It was determined that wave action would not substantially change the results for these highly disruptive water levels, therefore, it was not necessary to run the complex wave model.
Wave overtopping evaluation	Wave overtopping along the Embarcadero waterfront and along the finger piers was mapped with respect to safety level, particularly for pedestrians and vehicles. The evaluation indicates the overtopping rate (for example, cubic feet of water per second per linear foot of seawall or pier edge), using descriptive categories ranging from "safe" to "very dangerous."

Notes:

Stillwater - The stillwater level is the water level when waves are not present.

FUNWAVE - FUNWAVE is a high-resolution, phase-resolving wave model. For the MHRA, this model was used to evaluate waves near piers along the seawall as well as the wave-structure interaction.

SWAN - The Delft University of Technology SWAN (Simulating WAves Nearshore) model computes wind-generated waves in coastal regions and inland waters. For the MHRA, this model provided the potential range of wave conditions offshore, an important boundary condition for the FUNWAVE model.

3.2.4 Coastal Flood Hazard Key Findings

The following is a summary of results from the MHRA coastal flood hazard analysis.

The qualitative descriptions of the flood hazard are listed for 5 different sea-level rise increments (current, 1.1 feet, 2.2 feet, 3.3 feet, and 6.9 feet) at 3 different daily or extreme tide return periods (100-year extreme tide, annual king tide, and daily).

- **Today, coastal flooding hazard is relatively low**:
  - The 100-year extreme tide will overtop the shoreline between Pier 5 and Rincon Park causing disruptive flooding of the northbound Embarcadero roadway and blocking access to wharves and piers.
  - Annual king tides cause nuisance-type flooding along the shoreline of Pier 5 and Pier 14, occasionally reaching the northbound lane of the Embarcadero roadway.
  - Daily high tides do not result in any flooding.

- **With 1.1 feet of sea-level rise, expected to occur between 2035 and 2050 based on current City guidance, coastal flooding hazard will increase moderately**:
  - The 100-year extreme tide will overtop the shoreline between Pier 5 and Rincon Park, as well as along the Pier 43 promenade. Flooding is most severe at the foot of Market Street and reaches inland to Spear Street causing flooding of the BART and Muni underground.
  - Annual king tides cause nuisance type flooding at several locations of the shoreline between Piers 5 and Pier 14 and have a high likelihood of inundating the northbound Embarcadero roadway.
  - Daily high tides will start to cause nuisance-type flooding along the shoreline of Pier 5 and Pier 14, potentially reaching the northbound Embarcadero roadway with the added contribution of wind driven waves.
- **With 2.2 feet of sea-level rise, expected to occur between 2050 and 2080 based on current City guidance, coastal flood risk will increase significantly:**
  - The 100-year extreme tide will overtop most of the shoreline, causing significant flooding of the Embarcadero corridor and a few notable piers including Piers 45 and 39 and the Ferry Plaza.
  - Annual king tides will overtop the shoreline between Pier 5 and Rincon Park causing disruptive flooding of the northbound Embarcadero roadway and blocking access to wharves and piers.
  - Daily high tides will cause nuisance-type flooding at several locations of the shoreline between Pier 5 and Pier 14 and have a high likelihood of inundating the northbound Embarcadero roadway with the added contribution of wind driven waves.
- **With 3.3 feet of sea-level rise, expected to occur between 2065 and 2100 based on current City guidance, coastal flood risk will transform the waterfront and downtown of San Francisco:**
  - The 100-year extreme tide will overtop all of the shoreline causing extensive flooding of the Embarcadero corridor and much of downtown, with flood depths reaching 4 feet at the foot of Market Street. Almost all piers will experience overtopping (Figure 3-10).
  - Annual king tides will overtop the shoreline between Pier 5 and Rincon Park, as well as along the Pier 43 promenade. Flooding is most severe at the foot of Market Street and reaches inland to Spear Street causing the BART and Muni underground to flood.
  - Daily high tides will overtop the shoreline between Pier 5 and Rincon Park causing disruptive flooding of the northbound Embarcadero roadway and blocking access to wharves and piers.
- **With 6.9 feet of sea-level rise, expected to occur between 2100 and 2150 based on current City guidance, coastal flooding will overwhelm the waterfront on a regular basis:**
  - The 100-year extreme tide will flood almost all of the historically filled bay back to the original shoreline, submerging downtown with over 5 feet of bay water. Wave action could potentially reach second floor windows for structures near the shoreline.
  - Annual king tides will cause complete flooding of the waterfront and a large portion of downtown with flood depths averaging 3 feet and localized areas seeing more than 6 feet. All piers will experience overtopping and significant flooding.

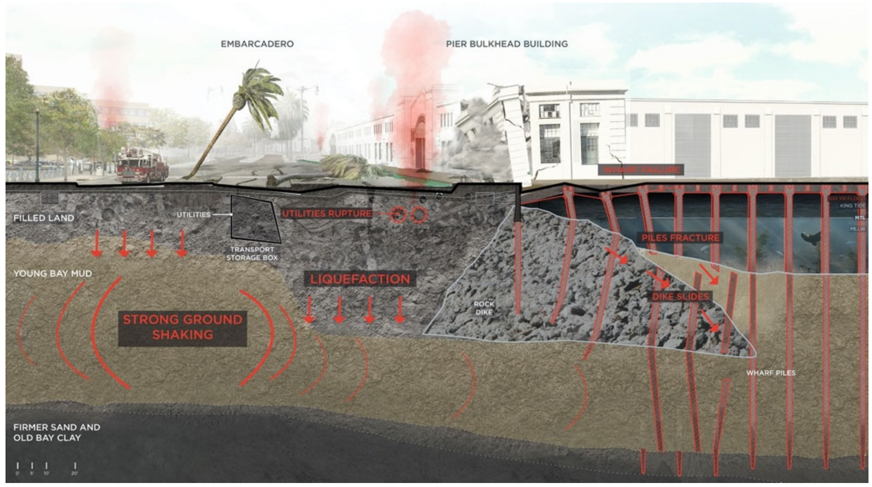
– Daily high tides flood will overtop all of the shoreline, causing extensive flooding of the Embarcadero corridor and much of downtown, with flood depths reaching 4 feet at the foot of Market Street. Almost all piers will experience overtopping.

Figure 3-10. Inundation Map for 100-year Extreme Tide under 3.3 Feet of Sea-level Rise

Note: Hatching indicates areas where wave action contributes to increased flood depth.

4 Findings by Discipline

4.1 Life Safety



Seismic events put buildings and lives at risk along the seawall

Source: CH2M/Arcadis Team, 2019

Earthquakes can strike suddenly and without warning, leaving no time for people to evacuate and move to safer areas. On the other hand, coastal flooding in the San Francisco Bay is largely predictable, which provides advanced warning time to prepare and move people to safety.

Buildings represent the highest risk to people during earthquakes and modern earthquake codes have focused on reducing the risk of collapse and of falling hazards such as heavy equipment and non-structural finishes that can injure people and block exits. In the urban environment, falling hazards from buildings and street infrastructure can also cause injuries and deaths. Fires are also a major risk because damaged utilities and buildings can cause leaks and ignitions, leading to fires and explosions. Most damage and many injuries in the 1906 earthquake were caused by fire. The May 2020 Pier 45 fire illustrated the difficulty of fighting fires on the piers.

The most profound issue about the waterfront is that most people are either very close to the water's edge or in buildings or open space located over the Bay rather than on solid ground. There are 115 acres of pier and wharf structures attached to the Embarcadero seawall that support more than 5 million square feet of buildings. On an average day, there are as many as 21,000 people on structures over the water, and as many as 38,000 during special events like fleet week, traveling from land to over water without many even noticing.

Each of the three seawall subareas plays host to distinct assets and attractions.

- **Fisherman's Wharf Subarea** is one of the most densely populated regions of Port property including large numbers of people at the overwater attractions and restaurants from Taylor Street to Pier 39.
- **Northeast Waterfront Subarea** includes key locations like the Ferry Building and Plaza, the Exploratorium, and the cruise terminal, which are highly populated. These occupancy hotspots sit alongside numerous smaller venues and offices, which contribute to the relatively high occupant estimate throughout the Port's property in this subarea.
- **South Beach Subarea** is more sparsely occupied; however, Oracle Park is a major draw and brings high activity levels along the promenade and queuing at the adjacent ferry terminal. The ballpark itself is a newer structure built to modern seismic standards.

Figure 4-1 provides an illustration of occupant density.

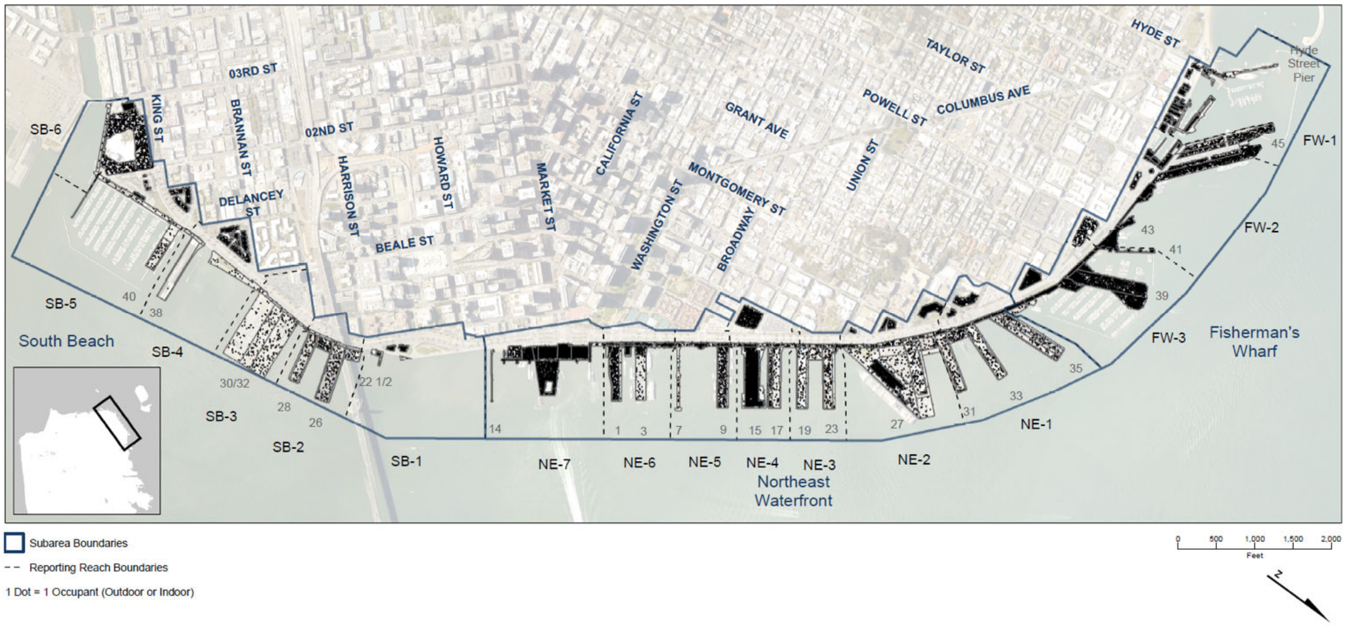


Figure 4-1. Illustration of Occupant Density

Note: This data and map were developed specifically for the Port of San Francisco planning level program-wide assessment and should not be interpreted as site-specific assessment. Dots are not drawn to scale. One dot represents one occupant under the peak occupant scenario, as defined for this analysis.

Basemap source: National Geodetic Survey, 2020

In general, the highest life safety earthquake risks are:

- **Wharves and buildings adjacent to the seawall are high risk due to seawall-related earthquake damage and consequences for promenade and pier access.** These facilities are much more likely to be damaged and have a higher potential for collapse and ignitions in very large earthquakes. In addition to the wharves and buildings, the adjacent promenade is highly occupied and damage to the seawall and wharves will limit landside access to the piers, complicating evacuation for thousands of people. The potential for damaging aftershocks can also cause life safety issues as people move to the waterfront for the purposes of evacuation and onto these structures before inspections and closures take place.

- **Unretrofitted historic pier sheds with concrete walls and flexible wood roof diaphragms are moderate to high risk.** These buildings are early examples of "tilt-up" construction and have weak connections of the wall panels to the roof, resulting in a partial collapse risk. Many original sheds are lightly to moderately occupied. Building codes have continually focused on making these connections stronger because the 1971 San Fernando earthquake and 1994 Northridge earthquake caused significant damage and partial collapses. Simple retrofits have proven effective at reducing collapse risk.

- **Utility damage to service laterals at the seawall is a high risk to cause fire to waterside buildings and timber marine structures.** Most wharves and piers are concrete and will not burn, however, most of the buildings are timber and many wharves in Fisherman's Wharf and some historic pier aprons and fender piles are timber. Even small movements of the seawall can break rigid connections, making this a high risk at the 100-year earthquake. Retrofitting with flexible service connections can greatly reduce the fire risk.

- **Rescue at isolated piers is a concern.** Damage at the seawall, the wharves, and the Embarcadero is predicted to limit the landside access to the piers potentially leaving people isolated. If there is damage, injuries, or fires break out, a quick waterside rescue may be needed. Many piers do not currently have small vessel berthing facilities such as ladders and fender piles that can facilitate rescue from skiffs, police boats, or fire boats.

Risk to life safety due to coastal flooding is considerably lower along the seawall, as there is significantly more time to predict an event and evacuate. The overtopping safety evaluation conducted as part of the coastal flood hazard analysis will inform discussions on when and where flooding could pose a particular safety risk to pedestrians and to vehicles. For example, under current sea level conditions, a 100-year extreme tide brings dangerous wave overtopping conditions for pedestrians in eight locations along the waterfront, the longest stretch of which runs from the Rincon Park to Pier 9. Similar safety concerns are anticipated on a daily basis under approximately 3.3 feet of sea-level rise.

4.2 Disaster Response and Recovery

St. Francis – The San Francisco Fire Boat

Source: Port of San Francisco

The Port plays a critical role in the City's and the region's overall disaster response and recovery. Due to its location adjacent to the Financial District, and its role in overseeing maritime infrastructure that facilitates water transportation and access to the Bay, the City's Emergency Operation Center, and downtown workers and residents will rely on the Port to provide operational assets in support of post-disaster missions such as firefighting and search and rescue, survivor evacuation, and debris removal. Over two dozen of the Port's facilities have a significant role in disaster response and recovery activities as shown on Figure 4-2. In addition, Port staff play a critical role in disaster response and recovery coordinating with local and regional operations, conducting prioritized damage assessments, and deploying skilled craftspeople for repairs and reconstruction before resuming normal operations. More specifically, the Port protects waterfront firefighting assets, such as Pier 22.5, Auxiliary Water Supply System (AWSS), and numerous drafting locations for the AWSS.

Disaster response and recovery refers to two broad phases following an emergency incident, defined as:

- **Disaster Response***:* The hours and days post-earthquake focused on life safety, damage assessment, and survivor evacuation. Assume a period of 4 or 5 days, the first 3 days of which are particularly critical.

- **Recovery***:* The weeks, months, and years post-earthquake focused on restoring utilities, executing repairs or reconstruction, and resuscitating core Port business functions before resuming normal operations. Assume a period of up to 3 years.

Each phase will call upon Port facilities and staff to support the City's overarching post-earthquake missions: life safety, damage assessment, survivor evacuation, debris removal, recovery facilitation, and business resumption.[6]

[6] A mission is a common purpose undertaken by the Port, the City and County of San Francisco, and associated governmental agencies. Each mission can be associated with one of the Department of Homeland Security's National Response Framework Emergency Support Functions, a guiding principle that helps organizations to provide a unified response to emergencies.

The results of the earthquake scenario analysis are summarized in Table 4-1 using a red-amber-green system to indicate expected damage levels for the key assets that support the six disaster response and recovery missions.

Figure 4-2. Disaster Response Assets in the Northern Waterfront

Note: This data and map were developed specifically for the Port of San Francisco planning level program-wide assessment and should not be interpreted as site-specific assessment.

Basemap Source: Mapbox, OpenStreetMap

Table 4-1. Asset Damage by Disaster Response and Recovery Mission and Earthquake Scenario

Disaster Response and Recovery Mission	Earthquake Scenario (Return Period)			
	43-Year	100-Year	225-Year	975-Year
Life Safety (Disaster Response)	Green	Yellow	Red	Red
Damage Assessment (Disaster Response)	Green	Green	Yellow	Red
Survivor Evacuation (Disaster Response)	Green	Yellow	Red [a]	Red
Debris Removal (Recovery)	Green	Yellow	Red	Red
Recovery Facilitation (Recovery)	Green	Yellow	Red [b]	Red
Business Resumption (Recovery)	Green	Green	Yellow	Red

[a] Exceptions: Ferry Building Gates E, F, and G (green), Ferry Building Gates B, C, and D (amber), and Pier 3 (amber)

[b] Exception: Pier 35 (amber)

Damage Code

Green	Negligible damage - Likely functional, minimal closure, some repairs likely.
Yellow	Medium damage - Likely repairable, impaired function and possible closure for repairs.
Red	High damage - Likely closed for repairs, may require replacement.

The disaster response and recovery assessment produced the following key takeaways:

- **All Missions***:* The Embarcadero roadway, a critical lifeline for every mission during disaster response and recovery, is expected to sustain damage along its entire length due to lateral spreading and settlement, especially at the 225-year and 975-year earthquake scenarios. The high damage predicted to the wharves and piers adjacent to the Embarcadero in the 225-year earthquake will also significantly impact all missions as these structures connect maritime facilities to the Embarcadero.

- **Life Safety (firefighting and search and rescue)***:* Hyde Street Harbor, including the attached fuel dock and nearby fuel dock tank farm, is the principal asset for the San Francisco Police Department Marine Unit search and rescue teams in the life safety phase of disaster response. This facility is expected to perform poorly in almost every earthquake scenario. The equally vulnerable Pier 22 ½ firehouse and fireboat complex will be replaced by 2022 with a highly resilient floating facility for both land and water firefighting functions.

- **Damage Assessment***:* Pier 1 will function as the central coordination location for both landside and waterside damage assessment efforts. The adjacent Pier 1 ½ will act as a rendezvous point for skilled tradespeople in skiffs from Pier 50 and engineers from Pier 1 to meet and begin conducting waterside damage assessments. Predicted damages at both locations in the 225-year and 975-year earthquake scenarios imperil the ability of the Port team to use those facilities as intended.

- **Survivor Evacuation***:* Ferry Building Gates E, F, and G are expected to be operational throughout all earthquake scenarios for survivor evacuation. With a passenger throughput capability of nearly 10,000 passengers per hour, safeguarding its operability from debris is vital. All other primary, supplemental, and alternate embarkation facilities are either impaired or closed by the 225-year earthquake scenario.

- **Recovery Facilitation***:* Of the six deep draft berths along the northern waterfront, the Pier 27 and Pier 35 cruise ship terminals are the only facilities expected to be at least partially operational after a 225-year earthquake scenario, though access to both facilities may be impaired from the Embarcadero and wharf damage. At the 975-year earthquake, Pier 35 is expected to be unusable and access is further complicated at Pier 27. When functional and accessible, these two facilities can efficiently receive, store, and manage large volumes of emergency supplies during the recovery phase. Earthquake damage that reduces or eliminates deep draft berthing capacity and staging along the northern waterfront could restrict the flow of supplies required for short-term recovery efforts.

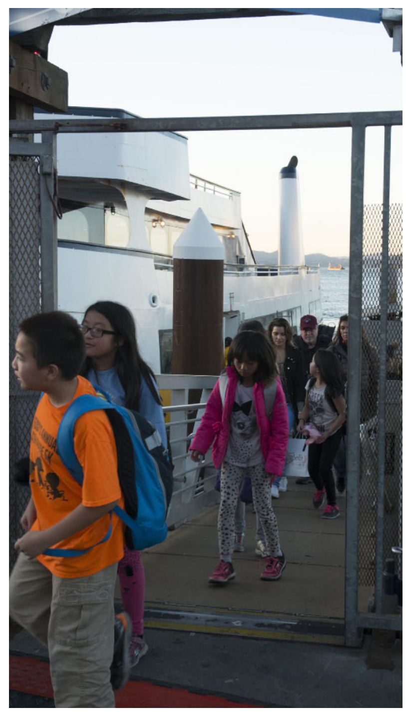
- **Business Resumption***:* Although outside the Embarcadero Seawall Program area, the Pier 50 Maintenance Facility is fundamental to conducting the necessary short-term repairs that would enable some Port tenants to quickly re-occupy buildings and resume business operations. The maintenance facility houses more than 100 skilled craftspeople in a wide range of trade categories. In addition, the shops, tools, and supplies at Pier 50 are essential for rapid repairs. In 2021, the Maintenance Division will acquire a heavy-duty piledriver that expands its marine reconstruction capability.

Disaster response and recovery assets are critical during an earthquake of unpredictable timing and magnitude. Major flood events along the seawall, by contrast, can be anticipated in sufficient time to protect disaster response and recovery assets before the arrival of floodwaters. Flood risk in general, including sea-level rise, must be considered as disaster response and recovery assets within the Port's jurisdiction evolve to meet future conditions.

4.3 Maritime Commerce

The Port's seven maritime industries – fishing, cruise, harbor services, temporary and ceremonial, excursion, water recreation, and ferry and water taxi – serve State purposes, and have important regional economic and social value.

- The Port is a State trustee, **responsible for promoting maritime commerce, navigation, fisheries**; protecting resources; and developing recreational facilities for public use. Port enterprise revenues from a broad tenant use portfolio fund capital repair and maintenance of maritime and public use functions.
- **Regional trade in international cargo and ocean fisheries commodities** are supported by harbor services and fishing functions that are not replicated elsewhere in the region.[7]
- **Regional tourism** is supported by cruise, excursion, and ferry services that are not replicated elsewhere in the region.[8]



Source: Port of San Francisco

- **Regional enjoyment of the Bay** is facilitated by water recreation, excursion, ferry, cruise, and ceremonial berth functions that are not replicated, or are scarce, within the region.

[7] Examples include the San Francisco Bar Pilots (provide essential harbor navigation services to regional trade) and the largest fish processing center in Central California.

[8] Examples include the only cruise terminals in the region, exclusive excursions to Alcatraz Island, and a regional hub of passenger ferries.

- **Critical disaster response and recovery services** are provided by all maritime infrastructure assets and functions, including for embarkation and debarkation; assembly and staging; berthing for deep-draft vessels; and centers for emergency response and operations.

Many maritime functions are disproportionately vulnerable to disruption due to the time sensitivity of maritime services and the dependence on their location along the seawall (Table 4-2).

- Maritime functions **depend upon water access and marine infrastructure**, thus cannot relocate upland in response to hazard disruption or damages.
- The **performance of most maritime functions depends upon a northern waterfront location** for proximity to ocean fisheries, the Golden Gate arrival point, or centers of tourism and employment.
- Most maritime functions perform **time-sensitive operations, such as commercial fishing, transportation and on Bay and shore services that need to be provided daily and** would be severely impacted by (or may not recover from) downtime for repairs to damages.

Table 4-2. Maritime Industry Characteristics

Maritime Industry	Time Sensitive Services	Function Depends on Location
Fishing	X	X
Cruise	X	X
Harbor Services	X	X
Temporary and Ceremonial		
Excursion	X	X
Water Recreation		
Ferry and Water Taxi	X	X

Earthquakes pose a particularly high risk to maritime functions with respect to access. **Vehicle access points along the bulkhead wharf are the weak link in an earthquake.** Without access, otherwise functioning maritime assets and operations cannot function. This affects all seven maritime functions beginning with the 100-year earthquake with related economic, regional, and social consequences.

Similarly, inundation and loss of access impact maritime function under coastal flooding conditions, with permanent flooding the primary concern. Temporary flooding caused by extreme, infrequent events are not anticipated to have significant direct impact on maritime function, even as the sea level rises. So long as the event does not cause widespread damage to key infrastructure, many maritime functions will resume once the storm has passed. However, **there is a tipping point between 3.3 and 5.3 feet of sea-level rise during which frequent floods and eventually permanent flooding are anticipated to cause the complete loss of maritime commerce industry function**.

4.4 Utilities

Suction connection for emergency firefighting, Rincon Park

Utility infrastructure along the seawall provides critical services for the Port as well as residents and businesses throughout the city. Utility systems, within the program area and beyond, are dependent on one another, and thus the process of understanding potential impacts of an earthquake or flooding is an inherently collaborative process. The utility assessment relied heavily on the data, input, and review provided by both public and private utility system owners. Port staff will continue to engage these key strategic partners in the subsequent phases of the Waterfront Resilience Program.

The six key utility systems are listed in Table 4-3, including key assets within the Embarcadero Seawall Program area.

Along the seawall, earthquakes and coastal floods pose a threat to this infrastructure in terms of both direct physical damage and limiting access for repairs and maintenance, which increase the time it takes to return the system to partial or full functionality. The wastewater system has the highest concentration of critical infrastructure within the Embarcadero Seawall Program area.

Table 4-3. Key Utility Systems and Assets Along the Embarcadero

Public Utilities		Privately Owned Utilities or Mixed Public/Private	
System	***Asset Summary***	***System***	***Asset Summary***
Wastewater (Combined Sewer and Stormwater) SFPUC, Wastewater Enterprise	• North Point Wet-Weather Treatment Plant and North Shore Pump Station • Transport-Storage Boxes • Combined Sewer Discharges • Buried Sewers (Pressurized and Gravity) and Service Laterals • Catch Basins for Stormwater	**Electric Power** SFPUC Hetch Hetchy Water and Power and CleanPower SF Enterprise[a] PG&E	• Shoreside Power (Pier 27) • Streetlights • Buried Distribution Lines • Service Laterals and Meters • Transformers • Buried Transmission Line
Low Pressure Water SFPUC, Water Enterprise	• Bay Bridge Pump Station • Buried Distribution Pipes and Valves • Low-Pressure Fire Hydrants • Service Laterals and Meters	**Natural Gas** PG&E	• Buried Distribution Lines and Valves • Service Laterals and Meters
Auxiliary Water Supply System SFPUC, Water Enterprise	• Pump Stations • Manifolds and Drafting Points • Buried Distribution Pipes and Motorized Valves • High-Pressure Fire Hydrants • Cisterns	**Telecommunications** AT&T Verizon Comcast San Francisco Department of Technology[a]	• Fiber Optic Cable (underground, underwater, on Bay Bridge) • Small Cell Towers (on buildings and streetlights) • Public Safety Radio Station at One Market Plaza

Notes:

PG&E = Pacific Gas & Electric
SFPUC = San Francisco Public Utilities Commission

[a] Public Utility

4.4.1 Earthquake Risk

Buried assets immediately adjacent to the seawall (within approximately 500 feet) were the primary focus of the utility earthquake risk assessment. The following is a summary of key findings:

- Ground displacement (lateral spreading and liquefaction-induced settlement), rather than ground shaking, is expected to drive utility damage, with significant damage occurring by the 100-year earthquake level. Damage is anticipated to be widespread with likely hotspots in the vicinity of the Embarcadero near Rincon Park, Pier 27, Piers 31-35, and Pier 39. The latter three of these hotspots are primarily caused by local ground displacement differentials where pipes cross a transport storage box or other large underground structure. To significantly reduce earthquake related utility damages, both liquefaction of the fill and instability of the seawall will likely need to be addressed.

- There is a dense network of buried distribution pipes for wastewater, water, natural gas, and electric power within 500 feet of the seawall. Key impacts from these four systems include the following:

  - **Wastewater**: Major disruption is anticipated for the 100-year earthquake and greater with sewage and stormwater flow likely blocked in multiple locations due to broken gravity pipelines, damage to the North Shore Force Main preventing the removal of sewage from the North Shore watershed, which provides sewer services for nearly half the population of San Francisco, and fracture of outfalls preventing outflow of treated effluent from the North Point Wet Weather Facility treatment plant.

  - **Low pressure water**: Water service disruption to nearby residents and businesses is anticipated in the 100-year earthquake event and greater. Addressing main breaks and rerouting of water will occur the first few days post-event, and repairs for areas with significant liquefaction will likely extend past 2 to 4 months with full system restoration taking 4 to 8 months.

  - **AWS):** Damage to key AWSS assets, while less than most utilities, is anticipated to have significant impacts on systemwide performance. Components expected to experience earthquake damage include system transmission line breaks, compromised access to 3 (out of 5 systemwide) fireboat intake manifolds, and compromised access to 20 (out of 35 systemwide) baywater suction manifolds. In addition, the critical saltwater intake tunnel for Pump Station No 1 runs through the seawall near Pier 38 and warrants further analysis.

  - Until AWSS distribution pipes are restored, redundant components of the AWSS and Portable Water Supply System will be used to fight fires. Even though AWSS shows less overall physical damage than other utility systems, performance of the AWSS distribution pipelines should be prioritized in any mitigation solution given the system’s role in life safety.

  - **Natural Gas**: Pacific Gas & Electric (PG&E) has already retrofit all gas distribution pipelines in the Embarcadero Seawall Program area boundary (and there are no transmission lines in this area). As such, the ductile steel and plastic distribution pipelines are expected to perform relatively well in larger events. Breaks and leaks are still possible, especially where very large ground displacements occur near the seawall. Service connections and laterals located near or passing through the seawall are expected to see damage. Significant secondary losses could be attributed to the natural gas system if a fire occurred after an earthquake, which have not been quantified in the MHRA.

- **Co-location of utility and transportation systems.** Utility pipelines run below the roadway, light rail, and promenade. Damaged utilities may impact the ability to use the road, and utility repairs or replacements will have major impacts on use during the work. In the event of a large earthquake, the severity of damages predicted to utility and transportation infrastructure suggests that full reconstruction of the Embarcadero may be needed.

- **Evacuation and Emergency Response.** Disruption to the utility and mobility systems will impact evacuations and emergency response for the 100-year earthquake level and beyond. Vehicle and pedestrian access will be slowed by the poor state of the roadway, potential flooding and ground failure caused by broken water mains, and potential overflow of wastewater onto the roadway. Potential breaks to the natural gas system and potential live electrical lines pose a threat to life safety while evacuation is underway.

4.4.2 Coastal Flood Risk

The following is a summary of key coastal flood risk findings:

- **Rising sea levels will reduce the hydraulic effectiveness of combined sewer discharges, which rely on gravity to drain into the Bay when they become overfilled**. Stresses to this key component of the wastewater system will become more severe over time and exacerbated by wet weather. Under 1.1 feet of sea-level rise, combined sewer discharges will not be able to discharge water during a 100-year extreme tide, and the North Point Outfalls will require pumping to discharge treated effluent from the North Point Wet-Weather Treatment Plant. This condition will become increasingly frequent as sea levels rise.

- **Overtopping and inland flooding will allow significant amounts of saltwater to enter the wastewater system, greatly increasing the volume of water that needs to be stored, conveyed, and treated**. Under 2.2 feet of sea-level rise, a 100-year extreme tide will allow significant floodwater to enter through catch basins and manholes and mix with both sewer and stormwater. Coupled with wet weather, this could overwhelm the collection system and cause inland flooding and flooding in buildings with fixtures below the flood elevation, which will then be conveyed to the lowest elevation via the city's roadways. In addition, the increased salinity in the wastewater system may impact treatment plant operations and increase corrosion rates of wastewater infrastructure.

- **Any effort by the Embarcadero Seawall Program to stop coastal flood waters from overtopping the current shoreline will extend the life of the combined sewer system** when paired with planned SFPUC upgrades to the combined sewer discharges.

- **Groundwater rise is expected to lead to a surge in maintenance and operation costs**. By 2.2 feet of sea-level rise, groundwater is expected to continuously saturate the bedding underneath buried pipelines and conduits, increasing the rate of degradation.

- **Floodwaters may enter conduits, boxes, and electrical equipment that is sensitive to flooding**. The AWSS seismically reliable motorized valves have underground battery vaults, that if inundated could render them inoperable. If buried water distribution pipelines are compromised, saltwater infiltration from increased groundwater levels could affect the quality of drinking water.

- **Drinking water service for Treasure Island and Yerba Buena Island could be disrupted under 3.3. feet of sea-level rise during a 100-year extreme tide**. Over 3,000 residents on these islands rely on the Bay Bridge Pump Station for drinking water.

4.5 Transportation

The seawall itself is the physical edge of downtown San Francisco. As such, it is the city's interface with the Bay, and the landing point from around the region. The City and Port have made significant investments to create a publicly inviting, pedestrian-oriented waterfront that draws tens of millions of visitors annually. City investments in the 1990s to replace the Embarcadero Freeway with an urban boulevard, public transit, and pedestrian promenade have been reinforced with significant additional pedestrian and water transportation investments along the Embarcadero. These systems include throughways and connections for essential regional and state assets such as:

The Embarcadero, the Ferry Building, and Ferry Building Gates

- Expanding regional ferry service
- The Bay Trail that rings the Bay with contiguous cycling and pedestrian access
- Regional rail crossing that serves the East Bay and beyond
- The Embarcadero and other roadways connecting to various modes or accessing nearby Bay Bridge on-ramps

As illustrated on Figure 4-3, the Embarcadero Seawall Program area provides for a wide range of transportation modes, and the vast majority of trips are spent on BART, SFMTA light rail, or walking. The assets and services available are provided, owned, and maintained by a variety of organizations, including and in collaboration with the Port. Beyond the Port, key partners and their primary services, include:

- SFMTA (Muni Metro surface and subway light rail, bus, cable car, shared responsibility for road, bike, and pedestrian facilities)
- San Francisco Public Works (shared responsibility for road, bike, and pedestrian facilities)
- BART (subway and transbay tube crossing)
- Golden Gate Bridge, Highway and Transportation District (ferry and regional bus)
- Water Emergency Transportation Authority (ferry)
- AC Transit (regional bus)
- Capital Corridor (regional bus)
- Sam Trans (regional bus)

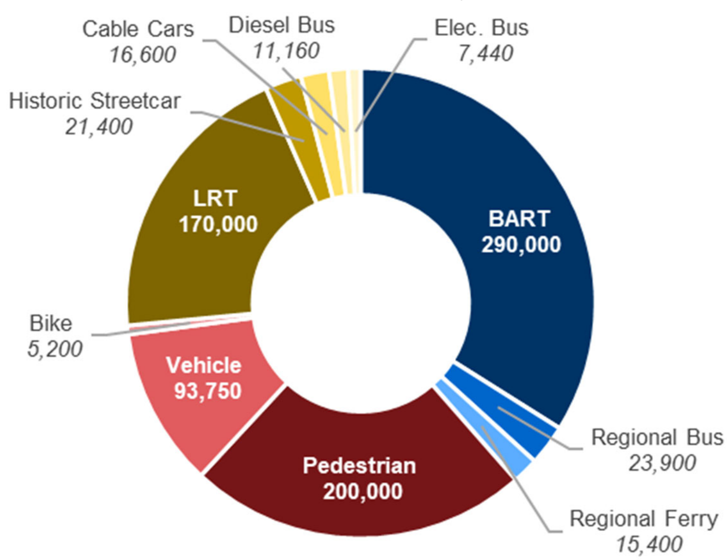


Figure 4-3. Relative Number of Trips per Day by Mode within the Embarcadero Seawall Program Area

LRT = SFMTA Light Rail Transit

Along the seawall, earthquakes and coastal floods pose a threat to transportation infrastructure in terms of both direct physical damage and limiting access for repairs and maintenance, which increase the time it takes to return the system to partial or full functionality.

4.5.1 Earthquake Risk

Surface transportation assets immediately adjacent to the seawall (within approximately 500 feet) were the primary focus of the transportation system earthquake risk assessment. The following is a summary of key findings:

- **San Francisco's transportation network is already at capacity with little redundancy or available capacity in any of its modes**. The loss of the Embarcadero roadway and Embarcadero promenade would result in additional congestion and reduced throughput on all modes in the surrounding area and have citywide and regional impacts.

- **Major repairs to the Embarcadero could take 6 months to 1 year following a 100-year earthquake, and severe damage following a 225-year earthquake would likely require complete reconstruction of some sections resulting in 1 to 2 years of construction and disruption.** The Embarcadero roadway repair time from a 43-year earthquake will likely be a few days for minor repairs, but no functional disruption is expected as local roads provide redundancy. After the 100-year earthquake or larger event, damage will be significant, with temporary repairs needed to support moderate recovery and permanent repairs (and partial closures) ongoing for 6 months to 1 year or more as repairs are coordinated with underground utility repairs and multiple public and private agencies.

- **Local transit will likely be out of service for at least a few weeks and could be out for over 1 year**. For a 43-year earthquake, the light rail trackway will likely be offline for 2 to 3 weeks, as checking and testing will be required even if damage is limited. This disrupts a total of 110,000 trips daily.[9] After a 100-year earthquake, surface light rail will likely resume in 6 to 8 months once local trackwork is complete, while the historic streetcars that depend on the special trackwork near Don Chee Way will likely be closed for up to 1 year. It is unlikely alternate bus service could be provided as roadways are also significantly damaged. These repair times will likely extend from 1 to 2 years for the 225- and 975-year earthquakes as full reconstruction of the Embarcadero becomes more likely.

- **Transportation system earthquake damage hotspots are primarily located along the Embarcadero in the Northeast Waterfront.** Due to the configuration of underground utilities, damage is likely to be most significant between North Point and Sansome streets (adjacent to Pier 31 through 35) and the Embarcadero between Broadway and Howard streets (adjacent to Pier 7 through Pier 14).

[9] 87,000 daily trips on the surface light rail (KT and N lines), and 21,400 daily trips on historic streetcars (lines E and F) (SFMTA, 2017).

4.5.2 Coastal Flood Risk

The following is a summary of key coastal flood risk findings:

- **Coastal flood risk to the Embarcadero roadway and promenade as well as streets in the Financial District will present a significant disruption to pedestrian, bicycle, and personal vehicle transit routes during and immediately after flood events in the short term, and complete disruption in the long term.** Today, king tides overtop a small portion of the seawall near Pier 14 and flood a few hundred feet of the Embarcadero promenade and northbound bike and vehicle lane a few times a year, causing localized flooding and limited closures of the promenade and northbound lane of the roadway. Under 1.1 feet of sea-level rise and a 100-year flood, portions of the Embarcadero and some side streets will flood, primarily at the foot of Market Street near the Ferry Building. By 3.3 feet of sea-level rise, a 100-year flood could expose the entire Embarcadero and 3 blocks of downtown, including the Financial District, residences, critical facilities, small businesses, offices, and commercial uses, and could affect vehicular, pedestrian, and bicycle routes. At 2.2 feet of sea-level rise, expected to occur between 2050 and 2075, the Embarcadero roadway and promenade reach a tipping point, where the 100-year flood causes widespread overtopping of the shoreline, resulting in complete elimination of function for multimodal movement with far reaching impacts to mobility patterns for both the city and region.

- **Underground transit systems, like BART and much of the SFMTA Muni light rail, are highly vulnerable to flooding**. Under 1.1 feet of sea-level rise and a 100-year flood, as water enters the system, flood damage and disruption could extend well past the program area. Disruption of these underground transit systems can displace approximately 460,000 trips per day and indirectly impact over 1.1. million trips per day in San Francisco. As the overall transit system is already running at capacity, limited opportunities exist for displaced underground transit trips to take advantage of alternative modes. Depending on the duration and extent of flooding, downtimes are expected to extend from a few weeks to years if both the Embarcadero Station concourse and mezzanine levels see damage.

- **The cascading impacts of severe and frequent mobility disruption, particularly to transbay trips, may result in regional transfer or loss of jobs and local businesses and threaten regional economic activity**. While regional transfers may result in economic benefit somewhere else, San Francisco's local economy, businesses, and services, and role in the region will be impacted.

- The groundwater table will rise in unison with sea-level rise. **By 2.2 feet of sea-level rise, the bedding underneath the Embarcadero roadway and SFMTA Muni light rail surface tracks will start to become continuously saturated, leading to a surge in operation and maintenance costs** for the critical Embarcadero transportation corridor.

4.6 Historic Resources

The Embarcadero Historic District is a nationally recognized historic district that has shaped the growth and design of San Francisco and the Bay Area. The district contains important historic assets (buildings and structures, including the seawall itself) with their own individual character and significance. These historic assets help define the public's waterfront experience and provide unique settings for commercial, cultural, and public uses. Along the Embarcadero seawall, there are 60 recognized historic assets including the seawall, bulkhead wharves, piers and buildings. Figure 4-4 shows the locations and construction periods of the historic buildings and piers.

Piers 21 through 17 with the Bay Bridge under construction in the background, 1930s
Source: San Francisco Historical Photograph Collection, SFPL

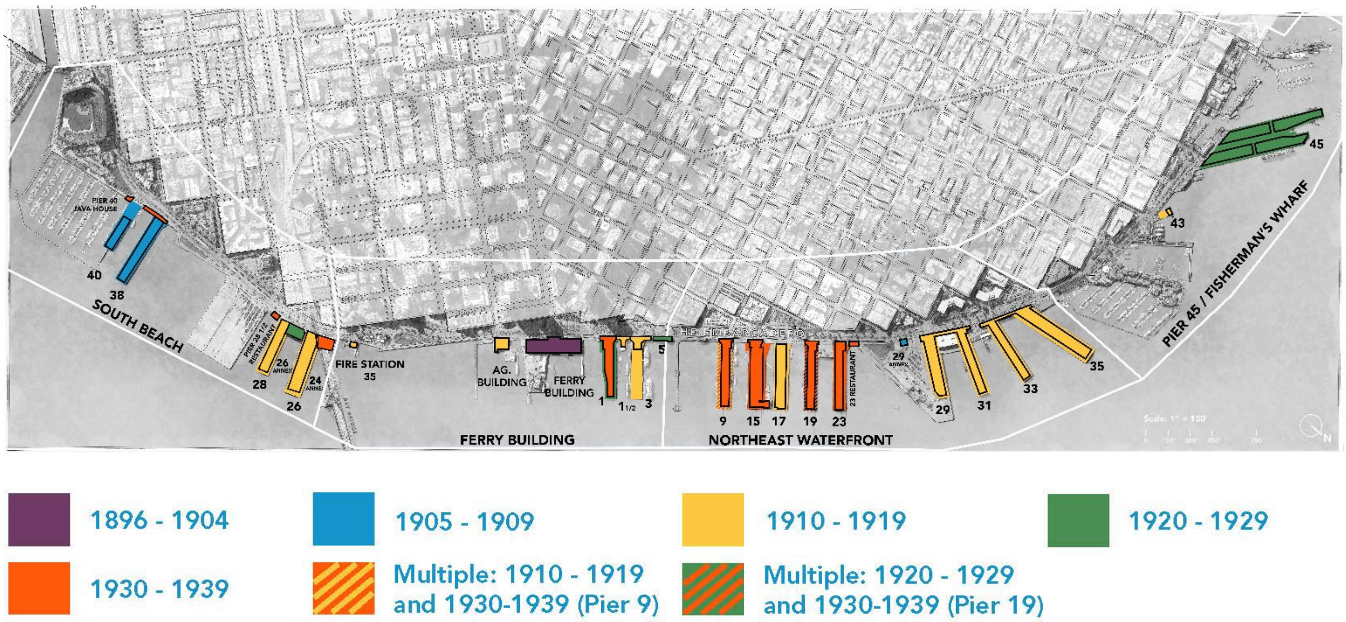


Figure 4-4. Historic Piers and Buildings by Construction Period

These buildings and structures are recognized locally and nationally as historic resources not only for their age, engineering, and architectural character, but also for their role in key historic events. The Embarcadero Historic District was the setting for the Pacific Coast Maritime Strike of 1934 (Big Strike), which had local and national impacts on politics and labor policy. It has also been a driver of commercial growth in San Francisco and the West Coast, acting as a center of local, national, and international transportation.

Due to the risks that earthquakes and future flooding pose to these assets, the district was named by the National Trust for Historic Preservation as one of the 11 Most Endangered Historic Places in the United States.

4.6.1 Earthquake Risk

Overall seismic risk to the Embarcadero Historic District is characterized as high, with widespread damage and some potential loss of resources expected in the 100- and 225-year earthquakes, and extensive damage and loss of resources in the very rare 975-year earthquake.

Tables 4-4 through 4-6 show the expected earthquake damage per historic asset category for each earthquake level.

- Earthquake risk is:
  - VERY HIGH for the bulkhead wharves
  - HIGH for the historic buildings
  - MODERATE for the piers

Table 4-4. Predicted Seismic Damage to Historic Bulkhead Wharves[a]

Earthquake Return Period	None/Slight to Moderate	Moderate to Extensive	Extensive to Complete
43-Year	**86%**	14%	0%
100-Year	14%	72%	14%
225-Year	0%	14%	86%
975-Year	0%	0%	100%

Table 4-5. Predicted Seismic Damage to Historic Piers[a]

Earthquake Return Period	None/Slight to Moderate	Moderate to Extensive	Extensive to Complete
43-Year	**100%**	0%	0%
100-Year	**94%**	6%	0%
225-Year	**67%**	**28%**	5%
975-Year	22%	**33%**	**45%**

Table 4-6. Predicted Seismic Damage to Historic Buildings[a]

Earthquake Return Period	None/Slight to Moderate	Moderate to Extensive	Extensive to Complete
43-Year	**100%**	0%	0%
100-Year	**90%**	7%	3%
225-Year	**36%**	**43%**	21%
975-Year	0%	7%	**93%**

[a] In Tables 4-4, 4-5, and 4-6, colors indicate values of 25% or higher.

- **As a group, the bulkhead wharves and bulkhead buildings represent the greatest risk**. Damage to or loss of the bulkheads would greatly affect the feeling of the district from the city side and could impact the district's integrity with regard to architecture, planning, engineering, and government.

- **The Agriculture Building and Section 8 (Ferry Building area) of the bulkhead wharf are the most at-risk historic assets**. The Agriculture Building is individually listed in the National Register of Historic Places (in addition to being a contributor to the district) so damage to or loss of this building could somewhat lessen the district's integrity.

- ***Overall Consequences to the district at each earthquake level are**:*

  – After a 100-year earthquake, a small number of bulkhead wharves and buildings could need full replacement due to complete damage. The U.S. Secretary of Interior's Standards for Reconstruction[10] provide guidance to determine whether reconstruction is an appropriate action based on: (1) a contemporary depiction is required to understand/interpret a property's historic value, (2) no other property with the same associative value has survived, and (3) when sufficient historical documentation exists to ensure an accurate reproduction.

Ferry Building, 1915

Source: San Francisco Public Library

  – Given the severity of damage predicted from a 225-year earthquake, repair or reconstruction might not be appropriate or feasible in certain cases. In this situation, the district could lose contributing historic assets. ***These losses could require a reevaluation of the existing district's size, shape, and historic significance***. Any reevaluation would need to include historic preservation stakeholders.[11]

  – A 975-year earthquake could cause significant impact to the district. The majority of bulkhead wharves, many buildings, and nearly half of the piers could need extensive repair or replacement. As in the other seismic scenarios, the appropriate Secretary's Standard would need to be considered for repair, retrofit, and replacement work. As with the 225-year earthquake, severe impacts to the district's integrity would need to be evaluated with local and national preservation stakeholders.

- **Seismic retrofits help preservation***:* Unsurprisingly, data predictions showed that seismic retrofit work is important in the performance of a historic asset during an earthquake. Of the 37 percent of buildings that remain only minimally damaged after a 225-year earthquake, over half have received retrofits.

In addition to direct seismic damage, earthquakes could have indirect consequences for buildings and structures. In the 1906 San Francisco earthquake, for example, subsequent fires resulted in extensive damage to buildings throughout the city. Flooding caused by damaged utility lines or sprinkler systems can also cause building damage. These types of indirect damages to historic assets within the Embarcadero Historic District should be considered as resiliency efforts move forward.

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[10] The Secretary of the Interior's Standards for the Treatment of Historic Properties are national historic preservation principles and guidelines that were adopted by the Port of San Francisco as part of the creation of the Embarcadero Historic District. Any modifications to historic assets should be consistent with these standards.

[11] Preservation stakeholders may include the Historic Preservation Commission, State Historic Preservation Officer, and National Park Service.

4.6.2 Coastal Flood Risk

While in the near term, only a few historic buildings are at an increased risk from intermittent flooding, these already vulnerable buildings are some of the most recognized and highly trafficked along the waterfront, including the Ferry Building, Agriculture Building, and Piers 1 through 5.[12] This region contains all of the district's individually listed assets (historic buildings that are individually significant in addition to being contributors to the overall district). Thus, a loss of assets in this zone could impact the district's integrity as well as the individual assets' historic recognition.

Over the coming century, storm activity and sea-level rise could have increasing impacts on historic assets and eventually most buildings could see daily flooding if no adaptations are put in place. Under 1.1 feet of sea-level rise, historic resources are anticipated to experience relatively minimal flood impacts. Under 2.2 feet of sea-level rise, the risk to historic resources increases to a moderate level of impact, both on an annual basis and in the event of a major flood event (such as a 100-year extreme tide). Under 3.3 feet of sea-level rise, the impact to the district is anticipated to be high, given daily flooding of key assets, assuming no preventative action is taken. Adaptation efforts as well as preservation, rehabilitation, restoration or reconstruction work after a flooding event should involve historic preservation stakeholders and be consistent with the Secretary of the Interior's Standards for the Treatment of Historic Properties.

From icons like the Ferry Building to working maritime buildings like Pier 45, the historic San Francisco waterfront represents a major civic and cultural resource that is at risk. The Embarcadero Seawall Program is an opportunity to protect and revitalize the many historic assets along the Embarcadero and ultimately create a stronger and more vibrant urban waterfront.

4.7 Buildings and Marine Structures

Along the 3.5 miles of seawall from Hyde Street Harbor to 3rd Street Bridge on Mission Creek are 115 acres of pier and wharf structures supporting 3 million square- feet of buildings and providing over 10 miles of waterfront edge. The majority of the waterside structures and buildings were built between 1907 and 1935. Landside of the seawall, there are approximately 50 Port-owned buildings and over 500 private- and City-owned buildings exposed to sea-level rise flooding. Each individual structure serves a variety of functions and economic activity. They are historic resources, places of work, social and cultural spaces, neighborhoods, small businesses, and critical services and spaces serving utility and transportation functions. In emergencies, they serve critical disaster response and recovery functions. Therefore, it is partially through an examination of the potential damages to buildings and marine structures that the Port will understand the economic and operational implications of earthquake and coastal flood risk along the waterfront.

Looking south toward several of the Port's overwater marine structures.

[12] Under current conditions, there is only a 0.02 percent chance in any given year of these buildings being exposed to flooding, and that likelihood would increase to 1 percent per year under 1.1 feet of sea-level rise and 10 percent under 2.2. feet of sea-level rise.

4.7.1 Earthquake Risk

The assessment includes earthquake damage and loss estimates for marine structures (piers and wharves), buildings on marine structures, and Port buildings on land influenced by the seawall for each of the four earthquake scenarios. Earthquake damage estimates are a function of the hazard components (ground shaking and seawall-related ground displacement) and the structural characteristics of the pier, wharf, or building.[13] Table 4-7 provides a summary of the earthquake damage results by main structure type.

Table 4-7. Structure Damage by Structure Type and Earthquake Return Period

Structure Type	Earthquake Return Period			
	43-Year	100-Year	225-Year	975-Year
Wharves	Minor	Moderate	Extensive	Very Extensive
Piers	Very Minor	Minor	Moderate	Extensive
Buildings over Water	Very Minor	Minor	Extensive	Very Extensive
Buildings on Land	Very Minor	Very Minor	Minor	Moderate

Note:

Structure type damage characterization is interpreted from Mean Damage Ratio results reported in tables 10-3, 10-11, and 10-27 of the Buildings and Marine Structures *Buildings and Marine Structures – Earthquake Exposure, Vulnerability, and Consequences Report,*. (CH2M, 2020a).

- **Overall, expected damages are greatest for the wharves and for buildings over water (for example, pier sheds), with piers performing somewhat better and buildings on land performing much better.** Wharves are uniquely vulnerable due to both ground shaking and instability of the seawall with moderate damage predicted at the 100-year earthquake and extensive damage from the 225-year earthquake. Damage to buildings over water is driven by the underlying wharf damage and by shaking damage to original historic pier sheds with concrete walls and flexible timber roofs.

- **The early 1900s concrete bulkhead wharves (Piers 22 ½ through 40) in South Beach, where the ground below the seawall is more stable, are highly vulnerable to ground shaking damage and potential collapse due to weak connections of the deck to the wall**. These are some of the oldest structures on the waterfront and can be improved with simple retrofits.

- **At the Ferry Building, the risk analysis supports the generally good performance observed in the 1906 and 1989 earthquakes but indicates that larger earthquakes, such as the 975-year earthquake, may cause significant damage to the foundation.** As shown on Figure 4-5, the Ferry Building substructure and seawall are unique on the waterfront, the area consists of extremely deep bay mud and there is a pile-supported concrete bulkhead wall instead of a rock dike seawall. Constructed in 1895, the substructure consists of massive unreinforced concrete piers capped with a shallow arched slab connected to the bulkhead wall and supported on over 5,000 timber piles. This is the only remaining structure on the waterfront that pre-dates the 1906 earthquake. *Because of the complexities of this location, that includes the BART tunnel running beneath and modifications over the years, additional detailed assessment can better inform risk.*

[13] Structural characteristics are based on assumptions informed by varying levels of structural data available. This analysis did not include site-specific structural assessments.

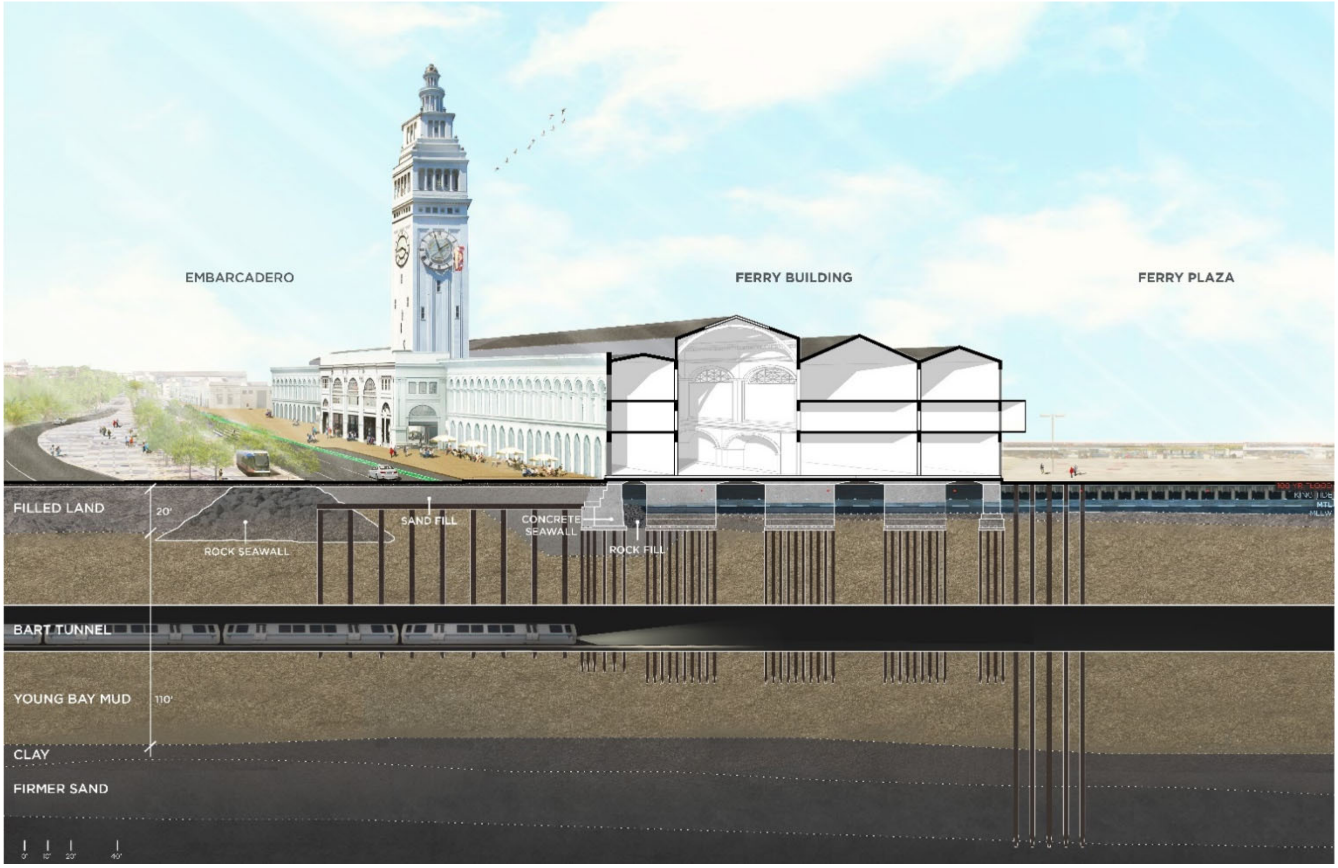


Figure 4-5. Cross-Section of Ferry Building Substructure

Source: CH2M/Arcadis Team, 2019

- **Extensive damage is expected where historic finger piers are rigidly connected to the wharves.** The finger piers and wharves were built together and will likely move differently during an earthquake (wharves shake quick and piers shake slow), resulting in a hotspot for damage to the marine structures and buildings.

- Other potential hotspots for significant structural damage include the Agriculture Building and substructure and many of the timber wharves and timber pile-supported buildings in Fisherman's Wharf. Again, detailed facility specific assessments may show different results.

- For all levels of earthquakes evaluated, the majority of piers did not pose a significant hazard of complete collapse. In most cases, the expected damage at higher earthquake levels reached an extent and severity that would likely cause extensive downtime and repair costs that could exceed the replacement cost of the structure.

- Although most damage is caused by lateral ground displacement, the damage caused by ground shaking is significant enough that strategic structural improvements are likely to be required at most locations in addition to seawall mitigation measures.

4.7.2 Coastal Flood Risk

While many key findings of the coastal flood assessment indicate consequences anticipated under future sea-level conditions and intermittent flood events, it is important to recognize that the port currently experiences minor coastal flooding at least once per year.

The MHRA coastal flood assessment includes consequences for buildings on Port property along the seawall and buildings within the floodplain beyond Port property. Building damage is a function of water depth and the structural characteristics of the building.[14] The following is a summary of the coastal flood damage results for buildings.

- The first Port buildings anticipated to experience physical damage include the Agriculture Building, Pier 5, Pier 1 ½, and Pier 3, and this damage would be expected with a 100-year extreme tide under current sea-level conditions. Prolonged restoration that causes economic or social disruption is not expected with one temporary flood event at this level, and repairs may not impede use of the building or require relocation of occupants.

- Between 1.1 and 2.2 feet of sea-level rise, the proportion of physical damage anticipated from a 100-year extreme tide shifts from being primarily on Port property to being primarily in the floodplain beyond Port property, which includes North Beach/Fisherman’s Wharf, Financial District, and South of Market/Mission Bay neighborhoods.

- Under 5.3 feet of sea-level rise, the floodplain behind the seawall is anticipated to experience major daily flooding (Figure 4-6) and be at risk of even more severe temporary events. Figure 4-7 presents one of the more extreme flood water levels mapped for this assessment, representing a 100-year flood with 5.3 feet of sea-level rise. By this time in the future, the proportion of direct physical flood damage to buildings beyond Port property exceeds that of buildings on Port property during extreme events, but Port property is regularly inundated with daily high tides. As shown on Figures 4-6 and 4-7, some buildings are anticipated to experience over 4 feet of water depth if no adaptation measures are in place.

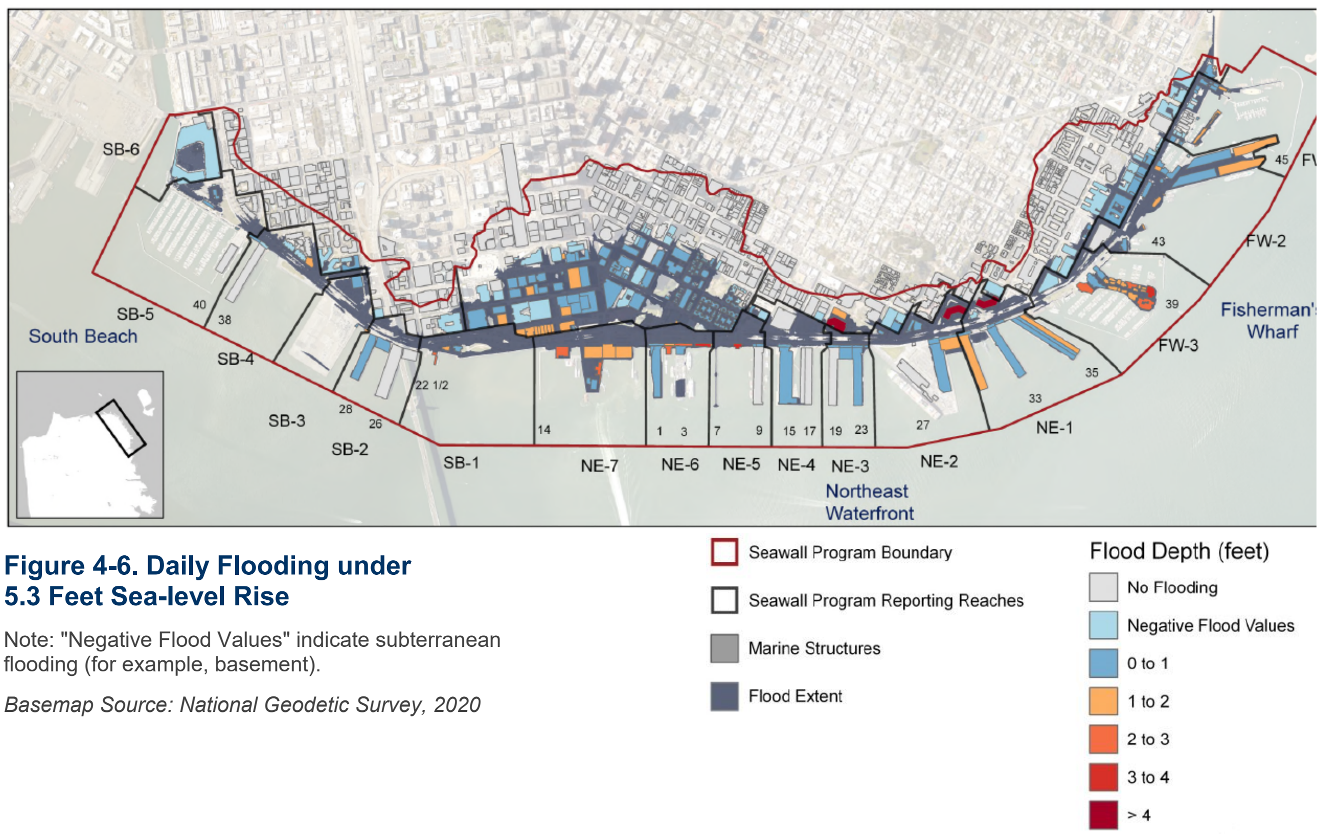


Figure 4-6. Daily Flooding under 5.3 Feet Sea-level Rise

Note: "Negative Flood Values" indicate subterranean flooding (for example, basement).

Basemap Source: National Geodetic Survey, 2020

[14] Structural characteristics are based on assumptions informed by building use, size, and elevation data available. This analysis did not include site-specific structural assessments.

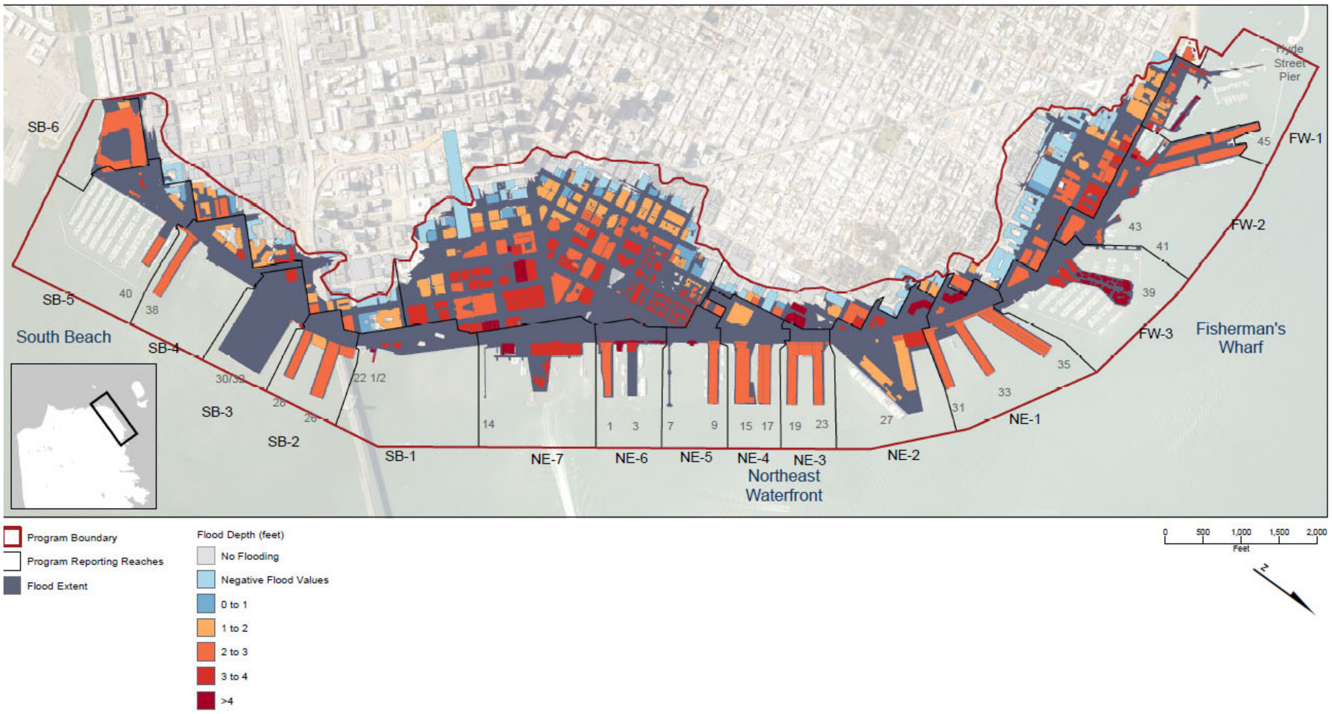


Figure 4-7. 100-Year Flood with 5.3 Feet Sea-level Rise

Notes: "Negative Flood Values" indicate subterranean flooding (for example, basement).

This data and map were developed specifically for the Port of San Francisco planning level program-wide assessment and should not be interpreted as site-specific assessment.

Basemap Source: National Geodetic Survey, 2020

4.8 Environment

In the 2019 Waterfront Plan Update, the Port reaffirmed its commitment to improve the ecology of the Bay and ensure “healthy waterfront neighborhoods through environmental sustainability, stewardship, and justice.” The San Francisco waterfront and shoreline is primarily an engineered and highly populated waterfront, which creates both constraints in terms of the diversity habitats, but also unique opportunities to connect many communities with the Bay. Therefore, the vitality of the land and water ecology and habitat present is all the more important to recognize, support, and enhance.

Watching sea lions at Pier 39

Source: Port of San Francisco

The MHRA included an assessment of the following with respect to earthquake and coastal flood risk:

- Soil, water, and sediment quality
- Key beneficial uses such as terrestrial and aquatic habitat, and commercial and recreational fishing that rely on healthy environmental conditions

Figure 4-8 presents an overview of the key environmental resources exposed to flood and seismic hazards along the seawall.

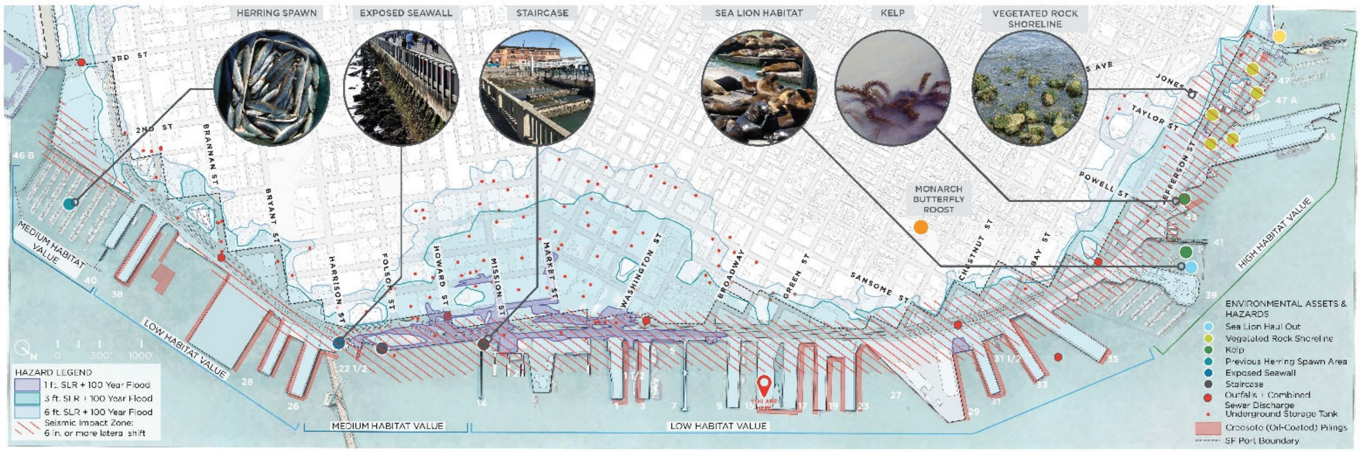
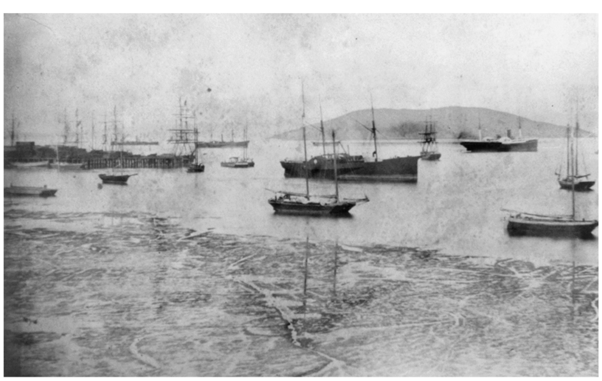


Figure 4-8. Map of Environmental Assets and Hazards

Source: CH2M/Arcadis Team, 2019

4.8.1 Soil, Water, and Sediment Quality

The waterfront area has been used for a great variety of activities since the middle of the 19th century. Historically, the shoreline of San Francisco was a mosaic of dunes, beaches, rocky cliffs, lagoons, and willow groves, with small patches of tidal marsh transitioning across a gradual slope to mudflats and deeper open water within the Bay. The discovery of gold in 1849 brought increased pressure for access by ships to San Francisco, eventually leading to the construction of the Embarcadero seawall. The seawall was constructed between 1879 and 1916 by creating a new shoreline in areas of deep water accessible to marine vessels. Backfill placed behind the newly constructed shoreline replaced the mosaic of natural shoreline habitats with developed land that is currently San Francisco's downtown financial district. With the new seawall came port, industrial, and commercial land uses, which included activities such as ship berthing, ship and vehicle fueling, storage and transfer of petroleum and other hazardous materials, railroad, and vehicle operations.



Historic photo of tidal mudflat from Yerba Buena Cove area.

Source: Port of San Francisco

As a result of this historic activity, a variety of potential sources of contaminants are present along and near the seawall, including:

- Groundwater and soil contaminated with materials such as diesel, gasoline, and heavy metals
- Creosote-treated piles supporting piers and wharves
- Underground and aboveground hazardous material storage tanks
- Toxins present in the water and sediment from prior releases, such as pesticides, mercury, and other heavy metals

Both earthquakes and flood events have the potential to increase contamination concerns. The principle concerns include:

- Existing onshore contaminants (including creosote on piles) could be mobilized due to either an earthquake or flood.
- Hazardous material storage containers could be damaged during an earthquake or flood, leaking contents into the surrounding area.
- An earthquake could cause large amounts of rubble and building debris to fall into the Bay and could introduce contaminants and cause disturbance of bottom sediments, which would mobilize contaminants and affect water quality.
- Flooding of urbanized areas at and adjacent to the Port would result in urban runoff into the Bay, which would contaminate Bay waters and sediment.

All above concerns could affect commercial uses, water-related recreation, or terrestrial or aquatic habitat.

4.8.2 Key Functions that Rely on Healthy Environmental Conditions

The primary functions or uses within the Embarcadero Seawall Program area that rely on healthy water quality in the Bay and the adjacent upland areas include commercial water uses, water recreation including fishing and swimming and other water sports, and aquatic and terrestrial habitat, The principle commercial water uses along the seawall include seawater use at the Exploratorium (heating/cooling), Aquarium of the Bay (aquatic life tanks), and commercial fishing.[15] Table 4-8 shows the potential earthquake and flood consequences on environmental functions.

Table 4-8. Potential Earthquake and Flood Consequences on Environmental Functions

Category	Function	Temporary or Permanent Potential Consequences[a]
Commercial Water Use	• Seawater for heating and cooling (Exploratorium) • Seawater for aquatic life tanks (Aquarium of the Bay)	• Disruption due to damage. Requires repairs or alternative system and water supply.
Commercial Water Use	• Commercial fishing boats and fishing charters[b]	• Damage to berth access and infrastructure. Requires repairs. • Fishing compromised by hazardous material spills or contaminated materials. Requires cleanup and time for natural dilution.
Water Recreation	• Water-contact recreation (for example, swimming, kayaking, kitesurfing, windsurfing, paddle-boarding, and wading) • Non-contact water recreation (for example, motorized boating, sailing, and wildlife watching) • Recreational and subsistence fishing	• Access restriction due to damage to embarkation areas and launches or due to hazardous materials and contamination.
Terrestrial Habitat	• Habitat for urban-adapted species (for example, pigeons, starlings, gulls, rats, mice, and skunks)	• Minimal appreciable consequences.

[15] Seawater is also used by the San Francisco Fire Department (Section 4.4).

Category	Function	Temporary or Permanent Potential Consequences[a]
Aquatic Habitat	• Constructed features (for example, walls, piles, piers, and rock revetments) • Subtidal habitats (for example, mud and open water) • Limited intertidal habitat (limited to rocky shorelines, sparse along the seawall)	• Displacement of habitat structures and the aquatic species that rely on them. • Disturbance (noise, visual, and disturbance of contaminated sediments) from cleanup of debris. • Exposure to hazardous materials and contamination. • Loss of valuable shallow subtidal and intertidal habitats (and associated loss of biodiversity) under higher sea levels. • Change and reduction of species under consistent exposure to contaminated urban runoff under higher sea levels.

[a] Applies to both earthquake and flood events unless otherwise noted.

[b] See Section 4.3

[c] The categories selected are consistent with the beneficial uses identified in the Basin Plan for the San Francisco Bay. (California Regional Water Quality Control Board, 2019)

4.9 Open Space and Parks

The sequence of parks, plazas, and open spaces connected by the Embarcadero promenade is the most significant continuous public realm for the many people that live, work, and visit the downtown and northeast areas of San Francisco. Together, there are more than 42 acres of public space adjacent to or over the water used by 85,000 people a day and valued at over $260 million. The Embarcadero promenade provides a single continuous path of travel along the shoreline, is the most critical part of this public realm, and is the primary means by which visitors to the waterfront access the majority of locations and services. Due to its linear nature adjacent to the seawall, it is also uniquely vulnerable to seismic and flood hazards, therefore, damages to the promenade will result in a significant disruption to transportation, commuting, recreation, and enjoyment along its entire length.

Locals and visitors from around the world enjoy and use the Embarcadero promenade.

Source: Port of San Francisco

4.9.1 Earthquake Risk

The consequences of seismic damage and disruption to the public realm are described primarily in terms of loss of function and access of the Embarcadero promenade to accommodate the many people who visit the waterfront every day.

- The 43-year earthquake is predicted to cause minor damage and result in minimal disruption to the use of the promenade. There will be some inconvenience due to higher damage near the Ferry Building and near Oracle Park.
- The 100-year earthquake is predicted to severely reduce the promenade function. It may be generally accessible, but many waterside destinations would be disrupted for a few months. In particular, areas near the Ferry Building, Fisherman's Wharf, and Oracle Park are likely to be significantly impacted, with the potential to affect access and use for approximately 570,000 users per month for a duration of 3 to 9 months.

- The 225-year earthquake is predicted to significantly damage much of the promenade, making it inaccessible and unusable to the public for up to 1 year or more for reconstruction (Figure 4-9).

- The 975-year earthquake is predicted to cause extensive to complete damage to the entire promenade, causing a complete loss of access and use for approximately 2.3 million people per month for a duration of 1 year or more.

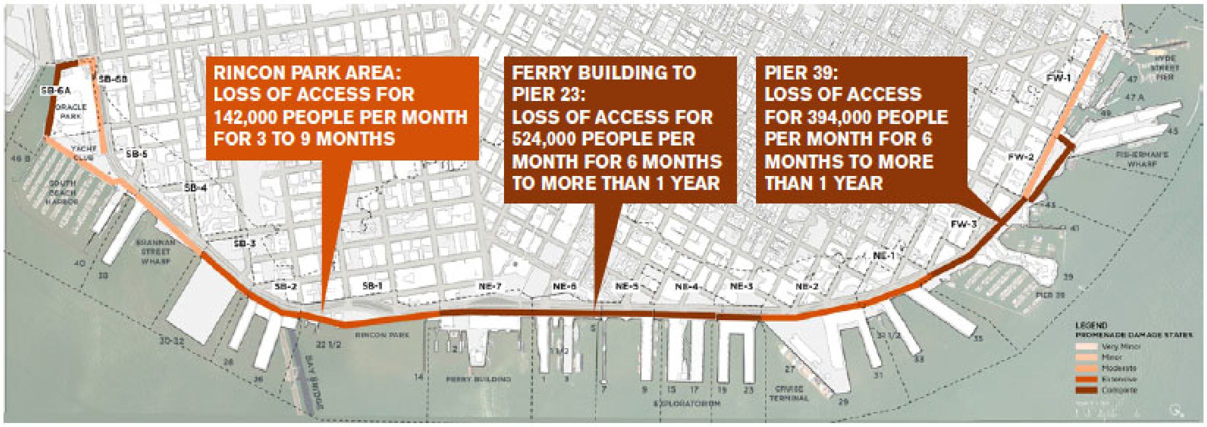


Figure 4-9. Promenade Damage Under 225-Year Earthquake

4.9.2 Coastal Flood Risk

The waterfront public realm generally consists of durable and resilient materials that are not predicted to have long-term impacts due to infrequent and short-term flooding. However, there a several planted areas along the waterfront at Rincon Park, Brannan Street Wharf, and other areas where flood waters from the Bay will damage these open spaces and require additional maintenance, closures, and possibly replanting of these areas. Even the most durable and resilient materials will require more frequent maintenance (cleanup and repairs) and operations (closures), and over time, will reduce the lifespan of these facilities. Additionally, community members with mobility challenges, including people with walkers, people with strollers, people on crutches, and people in wheelchairs will face more challenges travelling through or around flooded areas, making for dangerous conditions where water is present. While continuous, direct exposure to saltwater will degrade the condition of materials and elements of the public realm, the greatest concern for flooding of the public realm is how it impacts movement and access to public spaces along the waterfront.

- Coastal flood risk will impact different groups of people in different ways and at different thresholds. While limited amounts of infrequent flooding can be navigated by a typical healthy adult, it poses a significantly greater challenge to people with different mobility conditions and needs. For people with disabilities, children, or older adults, a flooded area of public walkways may pose a significant risk of injury due to slipping or falling that make areas of flooding inaccessible to them or require detours that extend the length and complexity of the trip.

- Under 1.1 feet of sea-level rise, a 100-year flood will disrupt travel in several areas along the waterfront including the Ferry Building area extending from Rincon Park to Pier 7, Pier 39, and Fisherman's Wharf. These are some of the most heavily transited and visited spaces along the waterfront and are critical to commuters, workers, tourists, community members, and others for daily trips and recreational use. This will disrupt the overall function of the public realm because many people enter or travel through those areas.

- Under 2.2 feet of sea-level rise, a 100-year flood will make the entire waterfront unusable and inaccessible due to widespread flooded areas. This same widespread inaccessibility would occur an average every 10 years under 3.3 feet of sea-level rise, and on a daily basis under 5.3 feet of sea-level rise.

Figure 4-10 presents an overview of some key open space and parks exposed to flood and seismic hazards along the seawall.

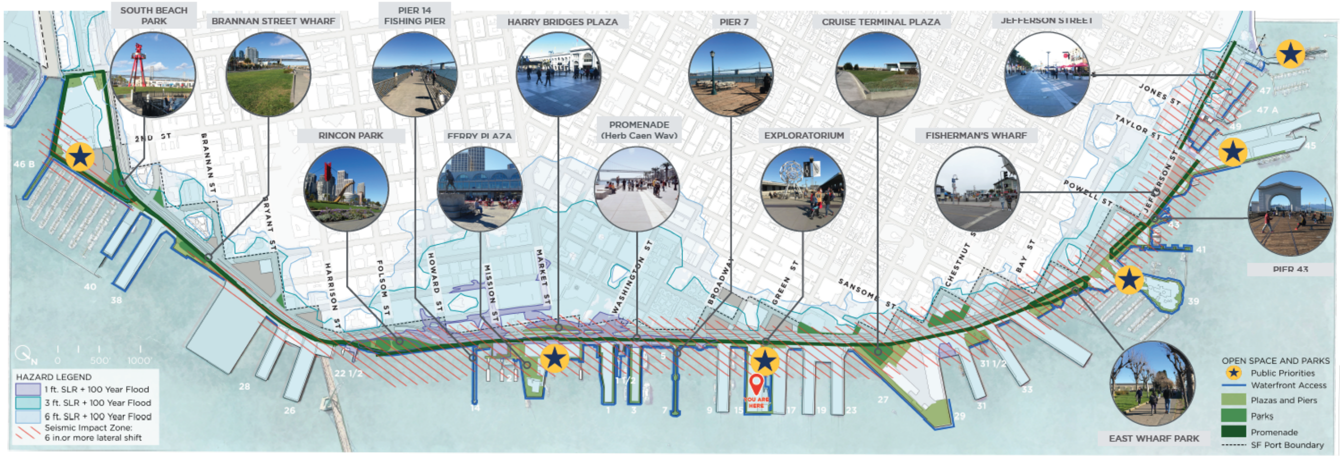
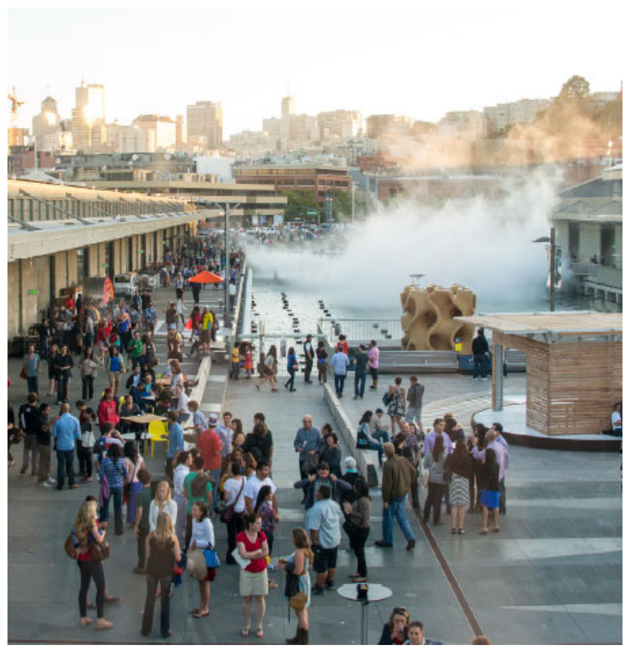


Figure 4-10. Open Space and Parks Exposed to Hazards

Source: CH2M/Arcadis Team, 2019

4.10 Land Use



Visitors enjoy the Exploratorium museum of science, technology and the arts at Pier 15.

The land use analysis assessed Port property along the seawall as well as parcels beyond Port property within the floodplain. On Port property, the pattern and scale of land uses reflect the Port's role of Trustee and administering the Public Trust for the State of California. The Public Trust requires that uses be consistent with the public's right to use California's waterways for navigation, fishing, boating, natural habitat protection, and other water oriented activities including swimming, preservation of land for scenic and wildlife habitat values, and historic preservation purposes. Public access and public use are cornerstones of the trust and uses that do not advance those values are not commonly found on trust lands. The Port's land uses also include uses that generate revenue to maintain and operate these public trust uses, as well as provide jobs, cultural and visitor serving uses. Many Port tenants are small businesses that provide vital services to the City and region. The mix of uses on the Port's properties with those within the adjacent neighborhoods of North Beach/Fisherman's Wharf, the Financial District, and South of Market/Mission Bay makes this one of the most dynamic parts of San Francisco.

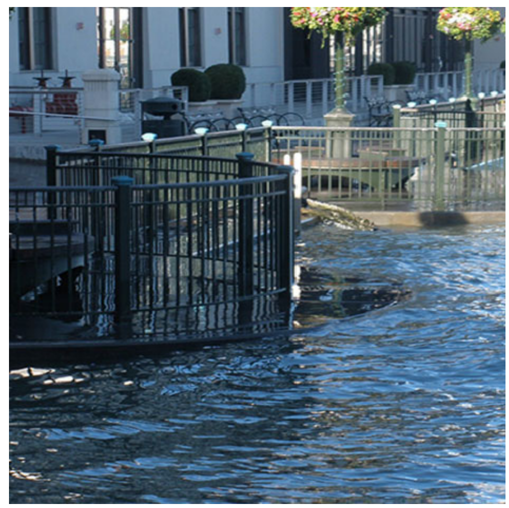
The interplay between the waterfront land and infrastructure, and the scale of piers and buildings, creates a unique set of uses and opportunities for a vital and resilient working waterfront. Within mixed industrial and maritime use areas, there are unique opportunities for inexpensive space that supports small businesses and restaurants. Piers provide opportunities for maritime functions, public use and public spaces, waterfront activation, historic preservation, and cultural and visiting serving uses that are connected by the Embarcadero promenade. Land use in the city to the west of the Embarcadero roadway, beyond Port property includes office and commercial uses, retail and restaurants, neighborhood serving uses and residential, critical public services, open spaces, hotel, cultural, and industrial uses. Table 4-9 presents land use parcel area by category.

Both earthquakes and coastal flooding pose a threat to the public trust land uses along the seawall, including maritime and industrial functions, commercial uses, and cultural and visitor attractions. These hazards also pose a threat to shoreline public open spaces, including plazas, public access, public piers, and the Embarcadero promenade. **Disruption to Port land uses would harm the Port's ability to generate revenue to maintain and operate public trust uses and serve the city, and would also harm the enterprise function and local and regional economy including a significant number of jobs and businesses** that rely on these facilities and functions.

The earthquake risk associated with the Embarcadero seawall and within the Port's jurisdiction is anticipated to have impacts across the various land uses. Severe seismic damages would be especially harmful to maritime operations, which require the piers and berths to operate, and would eliminate the unique community and regional benefits they provide. Earthquake damages are also projected to damage and disrupt many of the port's cultural and visitor serving uses that are located in the bulkhead buildings. This damage and disruption would severely affect the ability of the port to continue to serve as home to small business tenants, provide visitor and recreation uses, and host over 20 million people along the waterfront every year.

Table 4-9. Land Use Parcel Area by Category

Land Use Category	Percentage of Total
Mixed Office and Commercial	17%
Office	13%
Maritime	11%
Residential	11%
Commercial	11%
Public or Cultural Attraction	9%
Mixed Maritime and Industrial	6%
Open Space	6%
Mixed Commercial and Hotel	4%
Mixed Maritime and Open Space	3%
Hotels	3%
Institutional and Public Service	3%
Cultural	1%
Industrial	1%
Mixed Office and Residential	1%
Grand Total	*100%*



King tide at Pier 5.

Source: Port of San Francisco

- Coastal floods are anticipated to disrupt and damage different land use types due to temporary and permanent flooding. Public use of the waterfront, such as open space, commercial, and public or cultural attractions are disproportionally exposed to flooding, as is "mixed maritime and industrial" use. Open space and public or cultural attractions are anticipated to be disproportionately exposed to flooding under 1.1 feet of sea-level rise with a 100-year flood, and with increasing frequency as sea levels rise. Under 2.2 feet of sea-level rise, the 100-year flood continues to expose over 50 percent of institutional and cultural land uses and also exposes over 35 percent of the parcel area used for "mixed office and commercial" and "mixed commercial and hotel" uses. **By 3.3 feet of sea-level rise, extreme events such as the 100-year flood would temporarily expose well over 50 percent of the total parcel area in the Embarcadero Seawall Program area**, with disproportionate exposure of mixed maritime and industrial parcels, public or cultural attractions, open space, commercial, and mixed maritime and open space parcels. This severe level of exposure is anticipated during king tides under 5.3 feet of sea-level rise, and on a daily basis under 6.9 feet of sea-level rise. At the higher water levels over 3.3 feet of sea-level rise, much of the North Beach/Fisherman's Wharf, Financial District, and South of Market/Mission Bay neighborhoods would begin to experience more frequent flooding and at 5.3 to 6.9 feet of sea-level rise, a significant area of these neighborhoods would be inundated daily.

- Between 1.1 and 2.2 feet of sea-level rise, the proportion of physical damage anticipated from a 100-year extreme tide shifts from being primarily on Port property to being primarily in the floodplain beyond Port property.

4.11 Economic Cost of Inaction


The Embarcadero, Financial District, and Bay Bridge.

Source: Port of San Francisco

In addition to the risks to people and functions along the waterfront, earthquake and coastal flood damage and disruption within the Embarcadero Seawall Program area are likely to have significant economic consequences for the Port and the Bay Area if no preventative action is taken. The cost of inaction assessment includes financial consequences associated with damage and disruption to buildings and marine structures, utility systems, and transportation systems, with the critical assumption that no preventative actions are taken to reduce risks. These financial consequences include a combination of **direct physical damage** (for example, pipe breaks and pile fracture), **direct economic disruption** (for example, lost business income and wages), **regional economic losses** (for example, losses from the supply chain and income spending), and **economic consequences of social disruption** (for example, lost productivity due to mental stress and anxiety).[16] Consequences estimated for the Embarcadero Seawall Program were calculated using industry standards and models aligned with federal guidance.

This subsection provides an initial understanding of the economic risk reduction potential for measures implemented within the Embarcadero Seawall Program area. Key terms and concepts include:

- **Present value losses** represent future total losses over a specified time period, adjusted back to 2020. A 2.75 percent discount rate was used for the assessment in alignment with federal guidance.

- **Present value loss projections due to earthquakes and floods increase over longer spans of time, but only for flooding is this due in part to a changing hazard**.

  - By definition, the likelihood of a hazard event of a given *frequency* will be higher over longer periods of time. In any given year, the likelihood of a 100-year earthquake or a 100-year extreme tide is constant (1 percent chance of an event of this frequency or a more extreme every year). Over the span of 50

[16] Not all assets are assessed for each consequence metric. Direct physical damage, economic disruption, and social disruption assessments depend on the circumstances of the asset and the exposure to each hazard.

years, the likelihood of experiencing a 100-year event is more likely than in a single year (40 percent chance in 50 years).

  - The likelihood of a hazard event of a given *magnitude* stays constant for earthquakes,[17] but increases over time for coastal flooding due to sea-level rise. As illustrated in Section 2.2, a 100-year event under current conditions represents flooding at a water level that is more likely than a 100-year event in the future as sea level rises.

- **Direct losses** (direct physical damages and direct economic disruption) refer to losses experienced within the Embarcadero Seawall Program area. **Regional losses** refer to losses experienced elsewhere in the Bay Area as a result of the earthquake or flooding within the Embarcadero Seawall Program area.

4.11.1 Earthquake Risk

Earthquakes will have a major direct economic impact along the seawall, as well as an impact on the regional economy.

Approximately $800 million in direct present value losses can be expected over a 30-year period due to ground displacement and shaking hazards. This value includes risk of loss calculated including physical damages to Port marine structures and buildings, utility pipeline infrastructure under the Embarcadero, the Embarcadero roadway and light rail track, and direct economic disruption due to lost economic activity. Nearly 80 percent of these direct losses are derived from physical damage and economic disruption occurring because of impacts to marine structures and buildings within Port jurisdiction – over $630 million (Table 4-10).

Regional economic impact models increase the 30-year present value loss to $940 million when modeling the regional importance of the Port's jurisdiction and activities through the 9-county Bay Area. Without intervention, a 50-year regional present value loss may increase to $1.2 billion, and an 80-year regional present value loss may increase to $1.5 billion (Table 4-10).

The job sectors with the highest earthquake risk include restaurants (37 percent), and entertainment and media industries (within the seawall area these include Oracle Park, the Exploratorium, and television stations) (23 percent). These industries are most prevalent along the Embarcadero, a place of high public use, and represent sectors that depend on tourism and waterfront access to function at current capacity. Jobs within the program area and throughout California are expected to be impacted by earthquake activity within the program area.

The MHRA did not estimate the economic consequences of fire events following an earthquake in the Embarcadero Seawall Program area, however it is expected that fires could occur and would represent substantial potential economic damages. The well-known Shakeout Scenario for Southern California estimated that damage to buildings and their contents from fire events following an earthquake could account for losses that would be nearly 50 percent greater than those attributed to the ground shaking alone (Jones et al., 2008).

[17] Earthquake hazard can change as stresses build up and faults rupture, however, current state of assessment does not rely on a changing hazard over time.

Table 4-10. Earthquake Direct and Regional Loss Summary

System	Present Value Loss		
	2050 (30 years)	2070 (50 years)	2100 (80 years)
Marine Structures	$230,000,000	$310,000,000	$370,000,000
Buildings	$400,000,000	$520,000,000	$620,000,000
Utilities	$12,000,000	$16,000,000	$18,000,000
Mobility Infrastructure	$150,000,000	$200,000,000	$240,000,000
Subtotal, Direct Loss	*$800,000,000*	*$1,000,000,000*	*$1,200,000,000*
Regional Losses – Bay Area	$150,000,000	$190,000,000	$230,000,000
Total Direct and Regional Loss	**$940,000,000**	**$1,200,000,000**	**$1,500,000,000**

Note: Direct loss includes both physical damages and economic disruption. Economic disruption for buildings and mobility infrastructure represent direct economic disruption impacts. Economic disruption for regional losses include indirect (supply chain impacts) and induced (income spending) impacts expected throughout the Bay Area.

4.11.2 Coastal Flood Risk

With no intervention, coastal flooding made worse by sea-level rise will cause major economic consequences within the Port's jurisdiction and in adjacent neighborhoods, especially in the Financial District.

- **Risk of economic losses, including damage to buildings and infrastructure, economic activity losses, and mobility and social disruption, increases significantly between 1.1 and 2.2 feet of sea-level rise**. Damage and disruption losses jump from $180 million with 1.1 feet of sea-level rise to $570 million with 2.2 feet of sea-level rise. With 2.2 feet of sea-level rise, the 100-year extreme tide inundates most of the Port's facilities and a significant part of the future floodplain beyond Port property. The economic losses reflect increased risk on Port property and expansion of coastal flood risk into the North Beach/Fisherman's Wharf, Financial District, and South of Market/Mission Bay neighborhoods.

- **Direct and regional losses due to coastal flooding along the Embarcadero are expected to total $190 million over the next 30 years, $600 million over 50 years, and nearly $4.5 billion over 70 years, assuming the OPC likely sea level change projection** (Table 4-11). These loss projections assume the crossing of a major tipping point of 2.2 feet of sea-level rise near 2070.[18] Using the OPC 1-in-200 projection, 2.2 feet of sea-level rise occurs closer to 2050, in which case losses would occur substantially sooner. This only includes regional losses, such as losses in the supply chain and income spending, that are attributed to flooding within the Embarcadero Seawall Program area.

- **Business closure on Port property, in the Financial District, and in the North Beach and South of Market neighborhoods would cause reverberating market impacts through the rest of San Francisco, the Bay, and California, affecting the supply chain and household income spending patterns.** Thirty-three thousand jobs in the Embarcadero Seawall Program area could be exposed to a 100-year extreme flood event with 2.2 feet of sea level rise, with no intervention. These jobs are likely to experience short-term disruption during recovery. Sea level rise will also cause long-term disruption to jobs. As flooding becomes more frequent, 4,100 jobs may be permanently affected due to repetitive coastal flooding expected with 3.3 feet of sea level rise. Ninety percent of these jobs are in the restaurant, retail, and entertainment industries that are reliant on waterfront tourism. Regionally speaking, 3.3 feet of sea level rise at the Embarcadero and in the Financial District would affect an additional 2,400 jobs throughout the county and California. Jobs that

[18] According to the OPC Likely sea level change curve, 1.1 to 2.2 feet of sea-level rise may arrive between 2050 and 2075. (OPC, 2018).

support Port maritime functions will also be affected by repetitive coastal flooding. With 5 feet of sea level rise, 2,400 maritime jobs at the Embarcadero will experience disruption due to tidal flood impacts.

Table 4-11. Coastal Flood Direct and Regional Loss Summary Assuming California Ocean Protection Council Likely Sea-level Rise Projection

System	Present Value Loss		
	2050 (30 years)	**2070 (50 years)**	**2100 (80 years)**
Direct Losses-Embarcadero Seawall Program area			
Buildings	$79,000,000	$250,000,000	$1,700,000,000
Utilities	Not Available	Not Available	Not Available
Mobility Infrastructure	$98,000,000	$310,000,000	$2,500,000,000
Sub-Total, Direct Loss	*$180,000,000*	*$570,000,000*	*$4,200,000,000*
Regional Losses – Bay Area	$11,000,000	$31,000,000	$350,000,000
Total Direct and Regional Loss	**$190,000,000**	**$600,000,000**	**$4,500,000,000**

Note: Marine structures were not evaluated for coastal flood damages and disruption. Direct loss includes both physical damages and economic disruption. Economic disruption for buildings and mobility infrastructure represent direct economic disruption impacts. Economic disruption for regional losses include indirect (supply chain impacts) and induced (income spending) impacts expected throughout the Bay Area. Additionally, cost estimates due to damages and disruption to utilities were not available, however they are anticipated to be significant.

4.11.3 Overall Economic Risk

While earthquake risk and flood risk are distinct phenomena, it is important to understand their individual timelines, hotspots, and potential combined economic losses when considering their risks together.

- **The Northeast Waterfront presents the greatest combined earthquake and coastal flood economic risk in the near term due to the concentration of critical vulnerable transportation and economic assets** (that is, the Embarcadero roadway, Embarcadero Station, and Financial District), the deep bay mud ground conditions, and the lower elevation of the seawall. This is followed by Fisherman's Wharf, with South Beach presenting the lowest risk and expected losses over the next century.

- **The Northeast Waterfront is also the first subarea where coastal flood losses will exceed seismic losses**. According to the OPC likely sea level change curve, this may occur between 2070 and 2080 (OPC, 2018).

- **Total direct and regional losses from earthquakes present a higher risk in the near term, but the economic risk of flooding is anticipated to exceed that of earthquake risk between 2055 and 2080, based on OPC sea-level rise projections**. On Figure 4-11, the blue line indicates cumulative loss from earthquake risk, and the orange and green lines indicate cumulative loss due to coastal flood risk based on two key OPC sea-level rise projections. Flood damages in this figure include both Port and adjacent neighborhoods, whereas seismic damages are only represented for the Port.

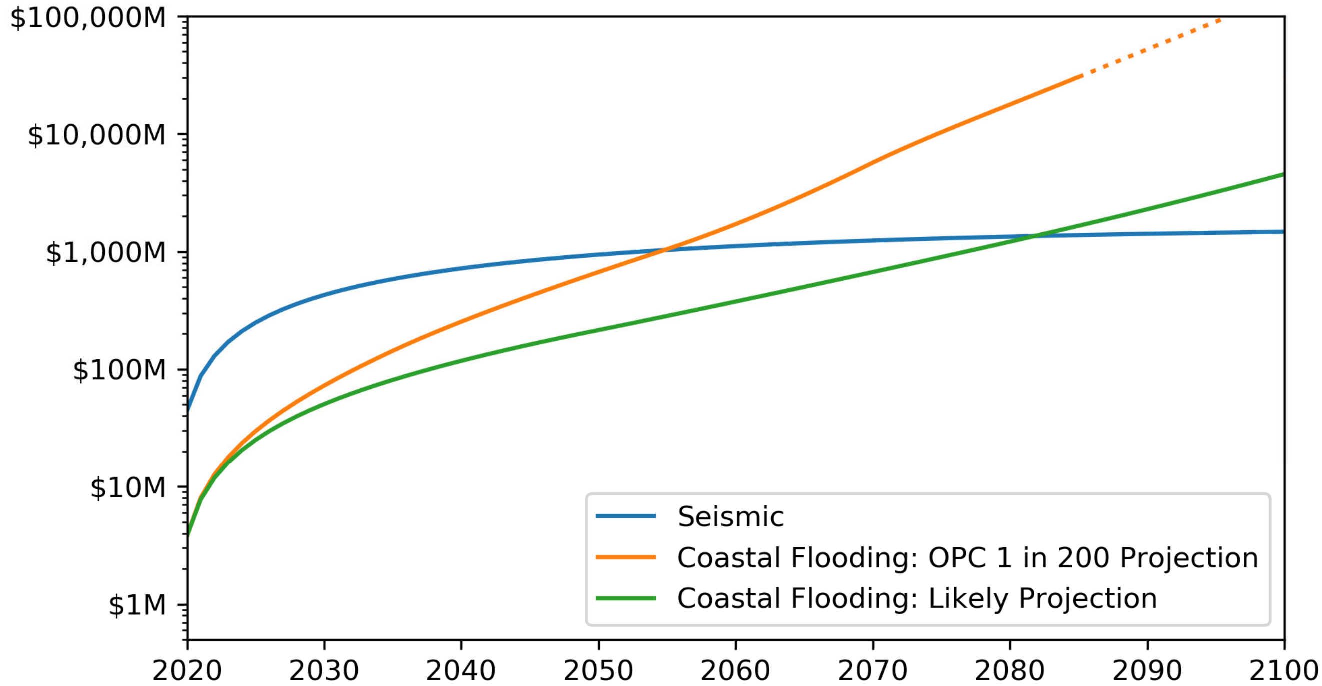


Figure 4-11. Cumulative Direct and Regional (Bay Area) Losses for the Entire Embarcadero Seawall Program (Buildings, Marine Structures, Utility, and Mobility)

5 Next Steps

The MHRA informs the Port, the City, regional partners and the public of the earthquake and coastal flood risk and consequences to people, the economy, and environmental and critical assets and services along the Embarcadero waterfront. It sets a baseline of risk and identifies the likely consequences based on the assets and services along today's waterfront.

This report is being published in the middle of the COVID-19 pandemic, which dramatically affects the focus of waterfront stakeholders, many of whom may be making critical decisions about their businesses or employment or the health of their families. The Port is mindful that as the important results of the MHRA – representing several years of intensive analysis – are shared, this is being done in midst of an ongoing pandemic that (1) distracts attention from these important findings, (2) emphasizes the importance of emergency preparedness, and (3) opens up new avenues for exploration that were not conceivable even 1 year ago.

While active work and life on the waterfront is seeing a pause in activity, the Port is confident that crowds and activity will return to San Francisco in the not-so-distant future and work must continue to improve the resilience of the waterfront to earthquakes and flooding. People rely on the San Francisco waterfront as a place of employment, a neighborhood to live in, a place to recreate, and an area that is much loved and visited by people from around the region, state, nation, and world.

The findings from the MHRA show there is work to be done to be better prepared for earthquakes and current and future flooding due to sea-level rise. These findings also illustrate where current work has improved resilience and reduced risks and consequences to these assets and areas. The new Ferry Terminal expansion project carried out by the Water Emergency Transportation Authority is truly a next generation essential facility resilient to earthquakes, lateral spreading, and sea-level rise. The planned fireboat station at Pier 22 ½ will also be resilient to earthquakes and flooding. The findings in the MHRA make the benefit of those actions clear and provide the opportunity to learn from these efforts as the Port advances near-, mid- and long-term resilience projects, starting with making the most effective and efficient investment of the voter-approved 2018 Proposition A Seawall Bond. These findings will also inform critical work underway in the Port's Historic Pier Rehabilitation Program.

The MHRA is a critical component in the Port's Waterfront Resilience Program and provides vital information for taking action to improve the resilience of the waterfront, reducing seismic and current and future flood risk. As the Port pivots from the MHRA and begins to use it and other information to develop and prioritize alternatives, the Port will:

- Continue to refine the vision, principles, and goals for a resilient waterfront based on the findings from the MHRA and input from community, tenants, decision makers, and other key stakeholders;
- Work with the Port Commission to define the evaluation criteria and decision-making process that will be used to develop staff recommendations and inform Port Commission decisions on future investments. This decision-making process will be clear; transparent; ties back to the vision, principles, and goals of the Waterfront Resilience Program; is informed by the key findings from the MHRA; and reflects input received through program engagement and communication work.
- Develop and evaluate a range of alternatives across the entire waterfront that address both seismic and flood risk that address the risks and reduce the consequences identified by the MHRA and reflect the priorities and concerns heard from community members, partners, and other key stakeholders. Alternatives development will be conducted in partnership with Port divisions and leadership, including the Port Commission, City partners, key stakeholders and community members.

- Continue the Waterfront Resilience Program's commitment to robust engagement and transparent decision making to ensure that program decision making is easy to understand and gains significant support among a broad range of stakeholders.
- Continue the San Francisco Flood Resiliency Study with USACE to complete the study and advance a tentatively selected plan for federal funding that meets the goals and objectives of the Port and the City and is USACE compliant for funding.
- Develop a portwide Adapt Plan with a framework to guide earthquake and flood resiliency efforts including policies, investments in shoreline flood protection including the seawall, and help guide capital investments in Port buildings and infrastructure that build toward the Port's vision of a safe, equitable, sustainable, and inspiring waterfront.

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