



SAN FRANCISCO BAY AREA  
**RISK** 2017  
**PROFILE**



# Association of Bay Area Governments

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## Foreword

This document was produced with support from the Bay Conservation and Development Commission (BCDC) Adapting to Rising Tides (ART) staff. Risk Profile 2017 is intended to synthesize information on Bay Area risks from current and future natural hazards. The research and data presented here comprise many state and federal resources that have been distilled to characterize the Bay Area's greatest risks.

The Risk Profile document was completed as many ABAG member towns, cities, and counties were in the process of updating their Local Hazard Mitigation Plans (LHMPs). Along with the document, ABAG and BCDC staff compiled resources to support the development of adaptation plans (hazard mitigation, climate adaptation, and safety elements). Valuable resources for resilience planning can be found at:

<http://www.adaptingtorisingtides.org/>

<http://resilience.abag.ca.gov/projects/2016-mitigation-adaptation-plans/>

All the maps in the document were generated with a geographical information system (GIS). They represent the best mapping data at the publishing date of this resource and are available for download on ABAG's Resilience Open Data webpage.

<http://resilience.abag.ca.gov/open-data/>

This document in parallel with other resources can help to regional and local stakeholders understand the risks Bay Area communities face. ABAG and BCDC are also committed to assisting jurisdictions in the development and implementation of resilience policies. More detailed information on resilience strategies can be found on the ABAG website.

The writing and production of this report was financed by the Federal Emergency Management Agency Cooperative Technical Partners Program, grant EMW-2014-CA-00101-S01. Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the Federal Emergency Management Agency.

A grayscale topographic map of the San Francisco Bay Area, showing the rugged terrain of the surrounding mountains and the intricate waterways of the bay and its tributaries. The map is oriented with North at the top.

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# EXECUTIVE SUMMARY

EXECUTIVE  
SUMMARY





## Executive Summary

# San Francisco Bay Area Risk Profile

Over the past several years, disaster mitigation, emergency preparedness and response, and disaster recovery have begun to coalesce, along with many other fields like environmental sustainability, social equity, and economic prosperity under the umbrella of resilience. Resilience itself is not a new concept. Cities and counties have long pursued various strategies to become more resilient, but have used a wide range of language to define, understand, and communicate what they are doing. Resilient actions may combine aspects of environmental sustainability, economic strength, risk management, emergency preparedness, and social strengthening. In the largest sense, a city's resilience is the collective capacity of individuals, communities, institutions, businesses, and systems to survive, adapt, and grow in the face of chronic stresses and acute shocks.



## A new approach to resilience

Historically, hazard mitigation planning focused on preparing for natural disasters by identifying ways to physically strengthen vulnerable physical assets such as essential service facilities or utility systems. Past planning processes have typically taken a narrow approach to make structures disaster-resistant. There has been, however, a fundamental shift in hazard mitigation to more holistic and cross-sector resilience planning. This practice can be seen in the context of other forms of long-term planning in communities that include general planning and budget development. Resilience planning is complementary to sustainability and climate action planning; synonymous in process to Climate Adaptation Plans; and is part of a suite of planning documents that enhance resilience at all phases of a disaster, including post-disaster recovery plans.

Traditional Local Hazard Mitigation Plans can include more holistic planning, analysis, and strategies for building resilience within jurisdictions. Additionally, these plans should be crafted to be useful beyond document production, with clear direction for implementing strategies that make communities safer.

Funding mitigation in annual budget decisions and other local projects enhances resilience. Well crafted Hazard Mitigation Plans can enhance eligibility to receive funding to implement actions before future disaster impacts, as well as during recovery from significant disasters.

## Vision for a Resilient Region

Improving regional resilience is a multi-faceted effort. By encouraging engaged residents; through, promoting effective local governance; supporting sustainable local and regional infrastructure; and, crafting decisions that promote large-scale problem solving, communities can make resilience progress. A resilient region can be built at many levels and exhibit some common characteristics. Resilient regions aim to be:

**Reflective** – stakeholders learn new practices, share what they learn, and adapt accordingly.

**Inclusive** – all members of the regional community are aware and knowledgeable and can provide input and perspective.

**Robust** – challenges and failure are examined for lessons learned, limited and contained.

**Flexible** – decision-makers are adaptive and devise alternative strategies as conditions/situations change.

**Integrated** – systems work together, interdependencies are known, and resilience solutions are incorporated into multiple contexts.

**Resourceful** – all participants look to acquire and repurpose resources to meet their needs.

**Redundant** – critical systems and supply chains contain backup systems in the case that one system fails.

This document provides many necessary technical resources for resilience-building at all levels, from residents and neighborhoods to cities and regions.

## Understanding Risk

Before communities or service agencies allocate mitigation resources, they must assess risk. Some public utilities in the region have extensively studied the seismic and flood vulnerability of their systems, resulting in implementing programs to upgrade systems. Many Bay Area cities have undergone similar extensive studies of city-owned building assets resulting in retrofit programs and land use planning that incorporate hazard mitigation.

To best apply mitigation resources, jurisdictions need to know their risk and develop solutions to both reduce vulnerabilities and address consequences. By mitigating vulnerability, potential damage can be reduced, and, in some cases, eliminated. By addressing consequences, risk is reduced by limiting the impact of damage or disruption caused by a disaster.

**Example of Reducing Vulnerability:** A multi-family housing complex built to an outdated code and near an earthquake fault undergoes an extensive seismic retrofit, decreasing the potential for severe damage in a future earthquake.

**Example of Addressing Consequence:** A city adopts a temporary housing plan to shelter residents in their own neighborhoods after a future disaster. By having the plan in place the likelihood of damage to homes is not reduced, but the consequences to the city from residents being displaced from the community are reduced. The plan helps keep social cohesion intact (neighbors are still living in the community) and helps protect the local economy (employees can stay in the area and continue to work and to make purchases within their community).

Understanding how people interact with buildings, infrastructure, and natural resources and how they can be impacted by natural hazards allows cities to proactively address risk. Using the information in the document, supplemented with locally specific information when available, communities can develop a detailed risk profile that can be used to draft strategies to address unacceptable risks.

## What you will find in this document

The San Francisco Bay Area Risk Profile brings together state and regional resources and distills the information into a single document summarizing the region's diverse natural hazard threats and the potential consequences when they occur. This document is organized into the following sections:

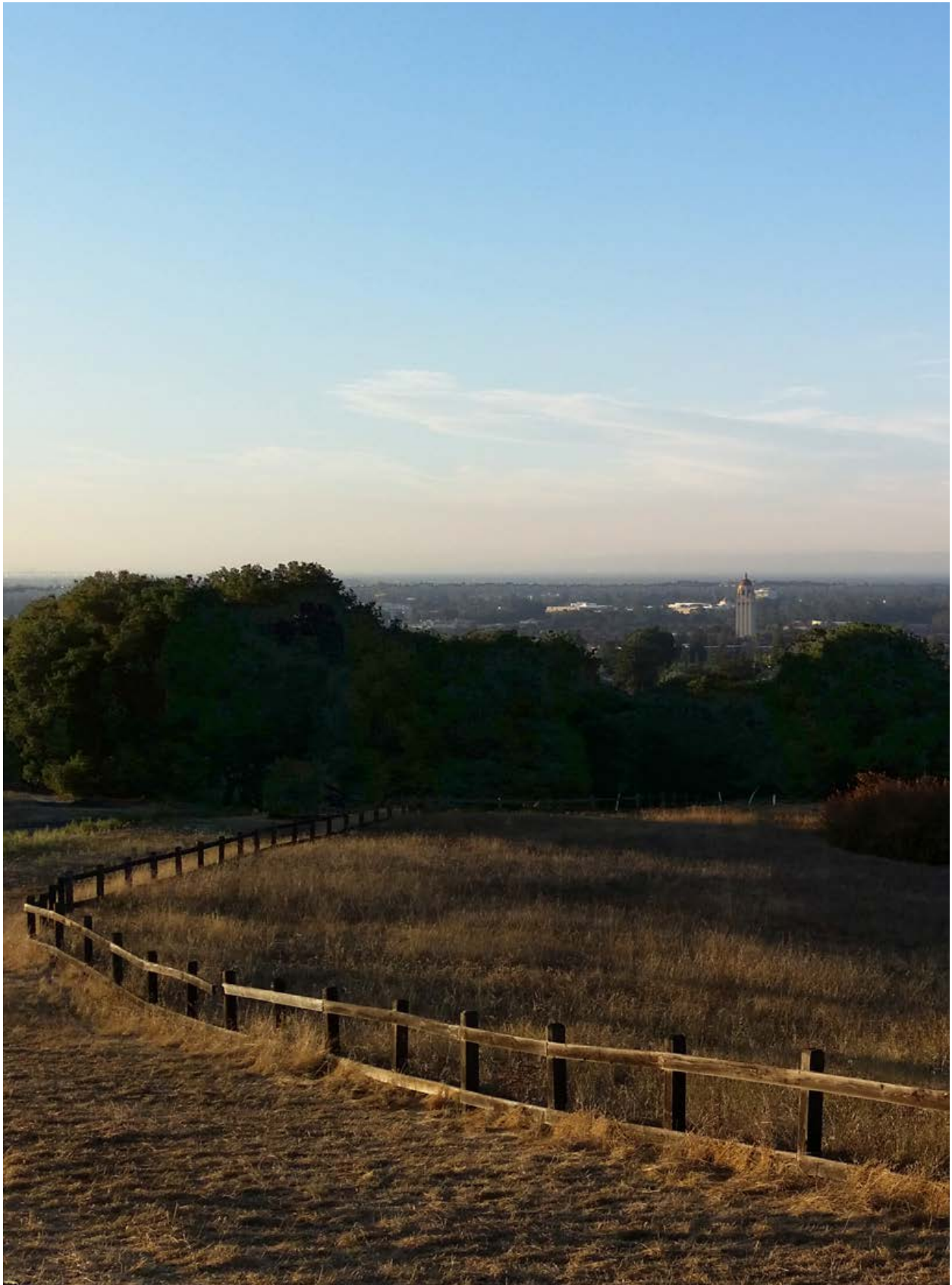
**Section 1 – Purpose & Scope:** Describes the audience for the document and the primary resources that inform the report. Readers are encouraged to use the primary resources directly for more detailed information, as well as inspiration for how a community can develop a substantial resilience assessment.

**Section 2 – Hazard Characterization:** Profiles natural hazards that pose significant risk in the Bay Area, some of which are expected to worsen with climate change. Earthquake (ground shaking, liquefaction, fault rupture, earthquake-landslide, tsunami, fire following earthquake), fire, flooding (storm, sea level rise), landslide (rain-induced, earthquake induced), drought, and extreme heat hazards are characterized with a detailed Bay Area focus. The resources used to map the hazards are available through an online open data portal on ABAG's Resilience Program website.

**Section 3 – Bay Area Assets at Risk:** Describes how people, buildings, infrastructure, and natural systems can be affected by a disaster and how each is vulnerable to hazards profiled in Chapter 2. The chapter does not complete regional level exposure of Bay Area assets, but provides communities with a process to effectively assess risks for multiple asset types.

**Section 4 – What Lies Ahead:** A call to action that moves communities to assess risks and mobilize resilience implementation.

**Appendix:** Provides a compendium of additional resources, worksheets, and templates to support local resilience planning efforts.



# PURPOSE AND SCOPE

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## Purpose and Scope

Risk Profile 2017 was developed specifically for the nine-county San Francisco Bay Area region based on a model document, New York City's Risk Landscape: A Guide to Hazard Mitigation, an innovative approach that transcended conventional hazard mitigation planning. In the San Francisco Bay Area Risk Profile, the Association of Bay Area Governments (ABAG) and Bay Conservation and Development Commission (BCDC) have characterized the historic and future natural hazards in the Bay Area and how these natural forces could affect the region's existing and future development. For **local governments**, Risk Profile is a resource to support development of resilience, hazard mitigation, and adaptation planning. For **regional agencies**, this report will inform and be integrated into regional efforts and plans including *Plan Bay Area*, the region's long-range transportation and land use strategy to accommodate future population growth and ensure a sustainable and resilient future for the Bay Area.

## Readers we want to serve

This document is intended for a broad cross-section of professionals in the region. City, county, regional, and special district jurisdictions engaged in hazard mitigation and/or adaptation planning are considered the primary audience. Other private and non-profit institutions interested in development, risk reduction, and resilience policy will also find value in the document.

## The primary sources for this document

The two primary sources used for the information in this report were the 2013 California State Hazard Mitigation Plan and the 2011 Multi-Jurisdictional Hazard Mitigation Plan for the San Francisco Bay Area. A number of additional state and regional resources and reports which provide updated, in-depth analyses into specific elements of Risk Landscapes were also used.

### California State Hazard Mitigation Plan (CalOES, 2013)

The State of California's plan was approved by FEMA on September 30th, 2013 as an Enhanced Mitigation Plan. The plan, in addition to identifying State mitigation strategies, contains an extensive description of natural and human-caused hazards, and documents progress made in hazard mitigation efforts. In Risk Landscape, many resources from the state plan have been extracted for the Bay Area region.

[hazardmitigation.calema.ca.gov/plan/state\\_multi-hazard\\_mitigation\\_plan\\_shmp](http://hazardmitigation.calema.ca.gov/plan/state_multi-hazard_mitigation_plan_shmp)

### California Climate Adaptation Planning Guide (CalOES & CNRA, 2012)

The State of California produced a resource to provide guidance and support for local

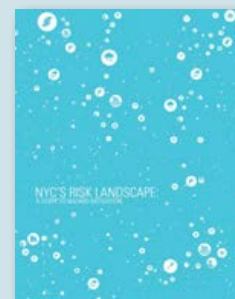
### New York City's Risk Landscape: A Guide to Hazard Mitigation

Following Hurricane Sandy in 2012, New York City sought to increase public awareness about the risks from a range of hazards that the City faces today and in the future. The report serves as a guide to the best available data on hazards that the city faces and promotes awareness of hazards to better inform preparedness actions by New Yorkers.

The report, an accompanying document to New York City's Hazard Mitigation Plan, was developed by the office of Emergency Management in partnership with the Department of City Planning and the Mayor's Office of Recovery and Resiliency. The report draws material from the much longer Hazard Mitigation Plan, but is more reader friendly and approachable for those not in the emergency management field. It serves as a key document to engage outside of traditional hazard mitigation communities to empower others to make resilient decisions.

Brevity was a key element of the guide's focus and scope. The information shared in the document is a subset of all hazards addressed in the Local Hazard Mitigation Plan to make the content manageable for readers. The *NYC Risk Landscape* document was a model resource that informed the Bay Area's Risk Profile materials. The document serves as a best practice for local governments interested in engaging the public in resilience planning. *NYC's Risk Landscape* is available at:

[www.nyc.gov/html/oem/html/planning\\_response/hazard\\_mitigation\\_risk\\_landscape.shtml](http://www.nyc.gov/html/oem/html/planning_response/hazard_mitigation_risk_landscape.shtml)



governments and regional collaboratives to address the unavoidable consequences of climate change. The document introduces the basis for climate change adaptation planning and details a step-by-step process for local and regional climate vulnerability assessment and adaptation strategy development. The guide was developed to allow flexibility in the commitment of time, money, and scope.

[resources.ca.gov/climate/safeguarding/adaptation\\_policy\\_guide/](https://resources.ca.gov/climate/safeguarding/adaptation_policy_guide/)

### **Taming Natural Disasters: Multi-Jurisdictional Hazard Mitigation Plan for the San Francisco Bay Area (ABAG, 2011)**

In 2010, the Association of Bay Area Governments led a multi-jurisdictional planning process with over 80 cities, counties, and special districts, which resulted in a multi-jurisdictional hazard mitigation plan and local annexes. Risk Profile is an update of the main content of that plan, but does not serve as a approved regulatory planning document. The 2011 plan contents have been updated with new information, and more completely characterizes the future risk of certain hazards due to climate change. The 2011 plan, as well as Risk Landscape, includes information and data from many technical sources including: U.S. Geological Survey (USGS), California Geologic Survey (CGS), California Office of Emergency Services (CalOES), Cal Fire (CalFire), Department of Water Resources (DWR), and Federal Emergency Management Agency (FEMA).

[resilience.abag.ca.gov/2011mitigation/](https://resilience.abag.ca.gov/2011mitigation/)

### **Stronger Housing, Safer Communities (ABAG, 2015)**

This report characterizes and maps vulnerable residents and housing types in the Bay Area region and has an accompanying manual with 40 residential hazard mitigation and adaptation strategies. The report maps three aspects of vulnerability: (1) fragile housing types that are likely to perform poorly if exposed to earthquakes

### **ADAPTING TO RISING TIDES (BCDC)**

The Bay Conservation and Development Commission leads an ongoing collaborative planning effort to help San Francisco Bay Area communities adapt to sea level rise and storm flooding. The Adapting to Rising Tides (ART) Program has engaged local, regional, state, and federal agencies and organizations, as well as non-profit and private associations, in an effort to increase the Bay Area's preparedness and resilience to sea level rise and storm events while protecting critical ecosystem and community services. The ART program recognizes that adaptation actions to reduce the vulnerability of the built and natural environment to the effects of climate change are a necessary complement to strategies to reduce greenhouse gas emissions.

Through the ART program, BCDC and its partners have gained a better understanding of how sea level rise and other climate change impacts will affect the Bay Area's ecosystems, infrastructure, and economy, and developed strategies to address these challenges. The ART program is a collaborative partner to ABAG, aligning regional planning processes to address hazards and risk and to support long-term safety, sustainability, and livability. The Risk Profile document incorporates ART materials in descriptions of flooding hazard (Chapter 2) and asset vulnerability (Chapter 3).

For communities interested in planning for sea level rise, BCDC has developed the online ART Portfolio with case studies, and how-to guides:

[www.adaptingtorisingtides.org](http://www.adaptingtorisingtides.org)



or flooding; (2) community characteristics that impede an individual or household's ability to prepare for, respond to, or recover from a disaster; and (3) areas where fragile housing and vulnerable residents are exposed to damaging earthquake and flooding hazards. Risk Landscape integrates a small portion of this extensive report in the people and buildings sections of Chapter 3: Bay Area Assets at Risk.

[resilience.abag.ca.gov/projects/stronger\\_housing\\_safer\\_communities\\_2015/](http://resilience.abag.ca.gov/projects/stronger_housing_safer_communities_2015/)

### **Cascading Failures: Earthquake Threats to Transportation and Utilities (ABAG, 2014)**

This report maps key Bay Area lifeline utilities, including airports, roadways, passenger rail, fuel, electric, and water systems, and analyses their exposure to, and potential consequences from, seismic hazards. Publicly available information was used to describe each system for a high-level picture of how the system operates and potential

consequences should the system be damaged. Risk Landscape synthesizes elements of the report in the infrastructure section of Chapter 3: Bay Area Assets at Risk.

[resilience.abag.ca.gov/projects/transportation\\_utilities\\_2014/](http://resilience.abag.ca.gov/projects/transportation_utilities_2014/)

### **Cal-Adapt (CNRA & CEC, 2016)**

This website is a resource produced by the State of California commissioned by the State's 2009 Climate Adaptation Plan. It is an online data repository used to visualize how climate change might affect California at the local level and is designed for local decision-makers to use when considering future hazard risks in California communities. The data hosted on Cal-Adapt was used to characterize how some Bay Area hazards can change in the future.

[cal-adapt.org/](http://cal-adapt.org/)

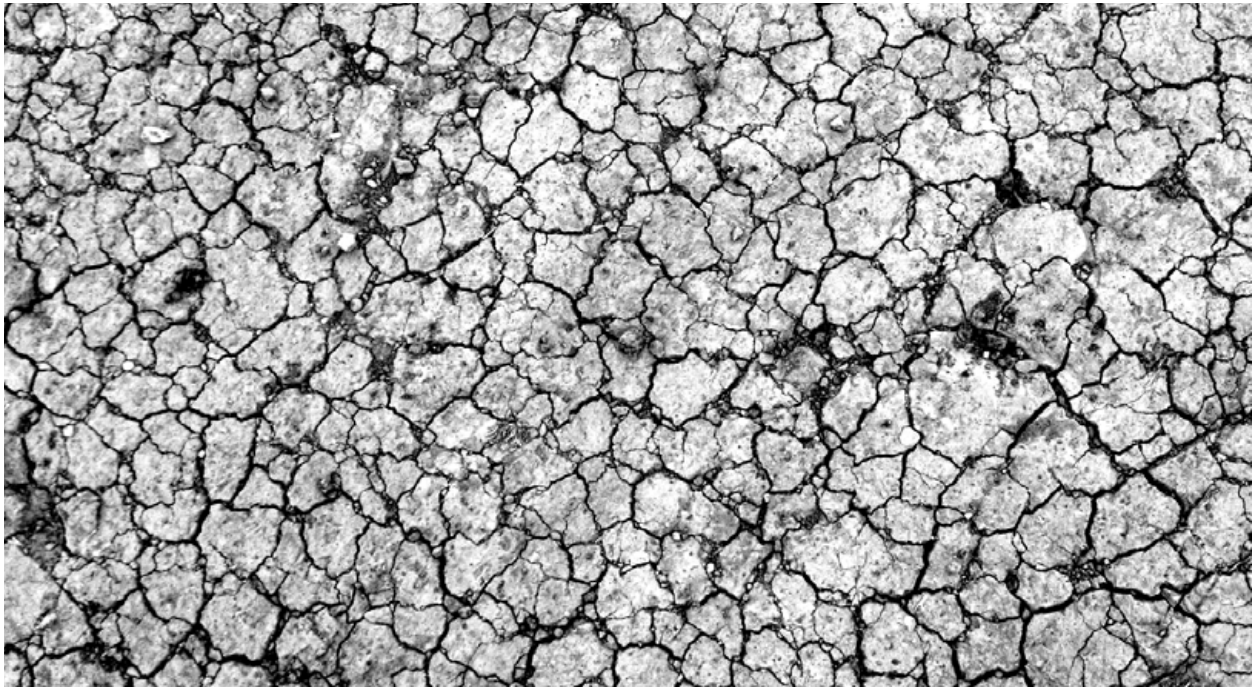


# HAZARD CHARACTERIZATION & RISK ASSESSMENT

2







# Hazard Characterization & Risk Assessment

The Bay Area's built and natural landscapes are shaped by natural forces. Faults and floods are responsible for the creation and erosion of our mountains, and past major disasters have changed where and how we develop. These natural forces will continue to shape the region, sometimes in brief disastrous moments, through the sudden release of massive amounts of energy in an earthquake or torrential influxes of water in a flood. Climate change will alter the location and severity of hazards, and those who live in the region will need to continue to adapt to the changing risk profile.

## Bay Area Hazards

This chapter defines and maps significant natural hazards that impact the people, built environment, economy and society of the San Francisco Bay Area. Each section describes a different natural hazard, including historic occurrences in the Bay Area, how hazards are likely to affect the region in the future, and what the affects will be including the potential location and severity of the different hazards within the region.

In the Bay Area, earthquakes are the hazard with the highest likelihood to cause extensive, multi-jurisdictional damage. All of the Bay Area is exposed to earthquake hazard, and impacts can cause region-wide disruptions. Disruptive earthquakes can occur at any given time. With the combined likelihood and extent of earthquake impacts, much of the focus of this chapter is on earthquake hazards.

Flooding, while less extensive in potential extent, is another major hazard that the Bay Area is exposed to, both along the bay and ocean shorelines and inland from rivers and streams. Localized flooding due to severe storms is fairly common, occurring, on average, once every other year. Temporary flooding and permanent inundation are also likely to become more extensive and severe in the future due to climate change. Localized flooding can cause significant impacts not only on local communities and assets, but on regional infrastructure and natural systems as well.

Other hazards may be less widespread or less frequent in the Bay Area, but can still cause significant local impacts and have cascading effects on the region. The most notable is wildfire, as the Oakland Hills Firestorm in 1991 still lives in the region's memory. Other hazards the Bay Area faces include landslides, drought, extreme heat, and dam and levee failure.

## Earthquakes

Earthquakes occur when two tectonic plates slip past each other beneath the earth's surface, causing sudden and rapid shaking of the

surrounding ground. Earthquakes originate on fault planes below the surface, where two or more plates meet. As the plates move past each other, they tend to not slide smoothly and become "locked," building up stress and strain along the fault. Eventually the stress causes a sudden release of the plates, and the stored energy is released as seismic waves, causing ground acceleration to radiate from the point of release, the "epicenter."

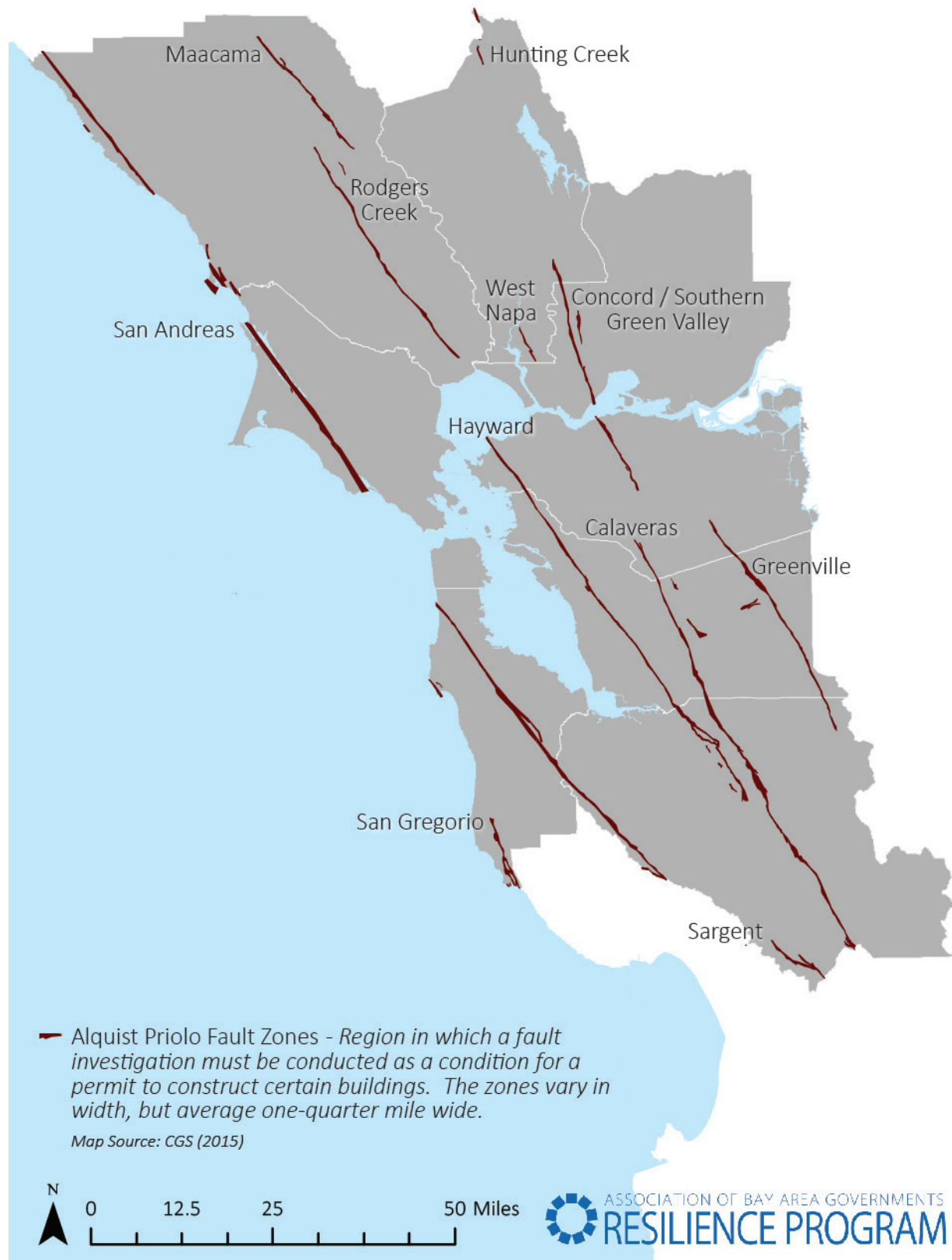
The Bay Area is in the heart of earthquake country. Major faults cross through all nine Bay Area counties. Every point within the Bay Area is within 30 miles of an active fault, and 97 of the 101 cities in the Bay Area are within ten miles of an active fault. Figure 1 shows the location of active faults that are mapped by the State of California under the Alquist-Priolo Act.

The total amount of energy released in an earthquake is described by the earthquake magnitude. The moment magnitude scale (abbreviated as M) is logarithmic; the energy released by an earthquake increases logarithmically with each step of magnitude. For example, a M6.0 earthquake releases 33 times more energy than a M5.0, and a M7.0 earthquake releases 1,000 times more energy than a M5.0 event (see Figure 2).

The quantified size or measurement of an earthquake is dependent on factors that include the length of the fault and the ease with which the plates slip past one another. In the Bay Area, technical specialists have observed varied fault behaviors, giving some sense of which faults may or may not produce a large, damaging earthquake. Earth scientists are most concerned about the San Andreas and Hayward faults, believed most likely to produce large, regionally damaging earthquakes. There are, however, many other Bay Area faults that can produce strong localized shaking and damage.

Additionally, earthquakes are often not isolated events, but are likely to trigger a series of smaller aftershocks along the fault plane, which can continue for months to years after a major earthquake, producing additional damage.

**FIGURE 1** Alquist Priolo Fault Zones



The energy released in earthquakes can produce five different types of hazards:

- Fault rupture
- Ground shaking
- Liquefaction
- Earthquake-induced landslides
- Tsunamis and seiches
- Fire following earthquakes

Each of these hazards will be discussed in greater detail later in this section.

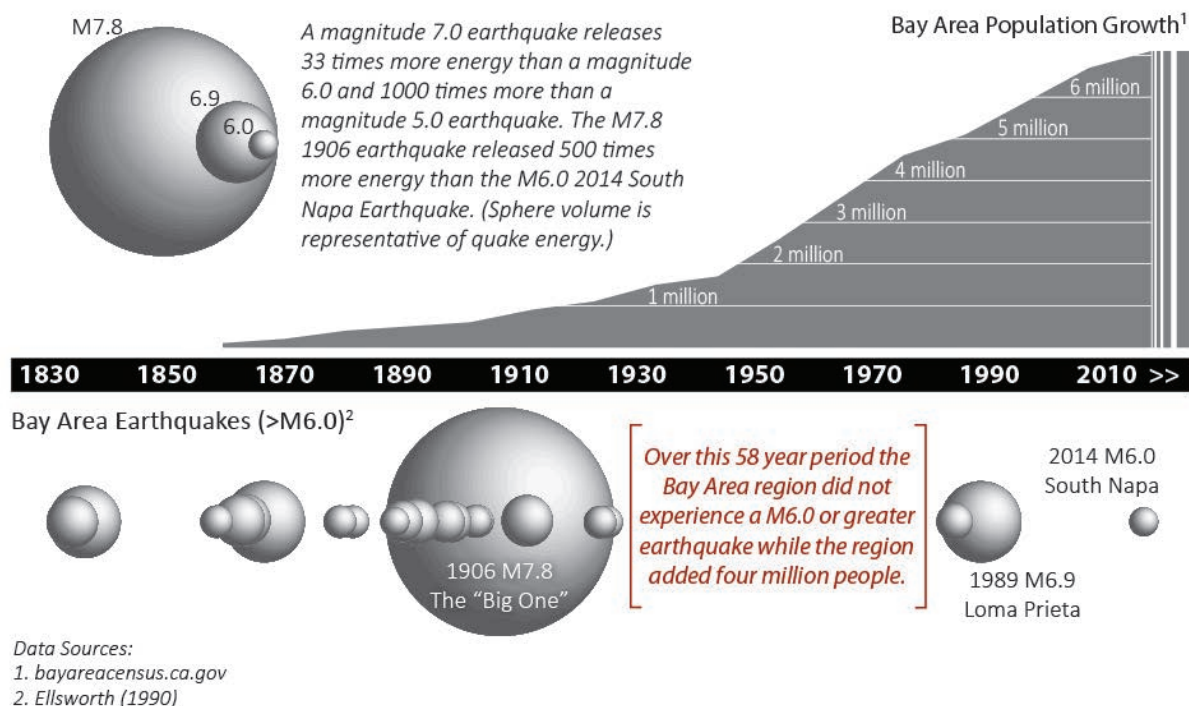
## Historic Bay Area Earthquake Occurrences

The Bay Area has experienced significant, well-documented earthquakes. In 1868, a significant earthquake occurred on the Hayward fault with an estimated magnitude of 6.8-7.0. The fault ruptured the surface of the earth for more than 20 miles and significant damage was experienced in Hayward and throughout Alameda County,

and as far away as San Francisco, Santa Rosa, and Santa Cruz. The M7.8 1906 earthquake on the San Andreas Fault, centered just off the coast of San Francisco, devastated San Francisco and caused extensive damage in Oakland, San Jose, and Santa Rosa. More recently, the M6.9 1989 Loma Prieta earthquake caused severe damage in Santa Cruz and the surrounding mountains, where it was centered, as well as fatal damage 50 miles away in Oakland and San Francisco. Moderate earthquakes are much more common in the Bay Area; twenty-two have occurred in the last 178 years, averaging every eight years. The 2014 South Napa earthquake is a reminder of the strong shaking that even a moderate magnitude 6.0 earthquake can produce in a localized area.

Figure 2 charts Bay Area earthquakes over the past 165 years. Because the 1906 earthquake released so much energy and stress on regional faults when it ruptured, the last 100 years have been relatively seismically quiet. As faults restore their stress and energy builds again, the region may have a more seismically active future.

**FIGURE 2** Timeline of Earthquake and Population Growth in the San Francisco Bay Area



**TABLE 1** Earthquake-related Declared Disasters in the Bay Area since 1950

Disaster	State Proclamation	Federal Declaration	Counties Declared	Damage
M6.0 South Napa earthquake	August 24, 2014	September 11, 2014	Napa and Solano Counties	\$362 million - \$1 billion in damage
Tsunami resulting from M8.9 Honshu, Japan earthquake	March 11, 1011	April 18, 2011	Del Norte, Monterey, Santa Cruz	\$39 million in damage
M5.2 Napa earthquake	September 6, 2000	September 14, 2000	Napa County	\$15-70 million in estimated damage
M7.1 Loma Prieta earthquake	October 18, 1989	October 18, 1989	Alameda, Monterey, San Benito, San Mateo, Santa Clara, Santa Cruz, San Francisco, Contra Costa, Marin, Solano	\$5.9 billion in damage, 23,408 homes damaged, 3,530 businesses damaged, 1,018 homes destroyed, 366 businesses destroyed
M6.2 Morgan Hill earthquake		April 25, 1984	Santa Clara County	\$7.265 million in damage to public, business, and private sectors
Tsunami warning resulting from Good Friday earthquake in Alaska	September 15, 1964	Not declared	Marin County	No damage

*State of California Multi-Hazard Mitigation Plan, Appendix M, California Governor's Office of Emergency Services*

There have been six earthquake-related declared disasters in the Bay Area since 1950 (see table 1).

### Probability of Future Earthquakes

A damaging earthquake similar to the 1906 earthquake or 1989 Loma Prieta earthquake are rare but likely to occur in the next 30 years. The United States Geological Survey (USGS) estimates there is a 72% chance of one or more magnitude 6.7 or larger earthquakes in the next 30 years on one of the Bay Area's faults. Smaller magnitude earthquakes are more likely to occur, potentially producing significant local damage, as experienced in the 2014 South Napa earthquake

Scientists continually study which Bay Area faults are more likely to produce large earthquakes, and how often. In March 2015, the USGS released an update to its 2008 earthquake probabilities

for California faults. The Uniform California Earthquake Rupture Forecast 3 (UCERF3) provides detailed assessment on the likelihood of each fault segment producing M6.7, M7.0 and M8.0 and greater earthquakes. These probabilities are based on data such as fault length; how much energy the faults release annually through fault slip; and, known historical return periods for the fault. Table 2 summarizes the probabilities of future earthquakes in California.

### Earthquake Hazard in the Bay Area

Earthquakes can trigger multiple types of seismic hazards, causing varying severity of damage in different locations. The following sections describe each earthquake hazard in greater detail, including where and how it is likely to affect the Bay Area.

**TABLE 2 Likelihood of a M6.7 or Greater Earthquake Over the Next 30 Years**

Earthquake Fault	Probability <sup>1</sup>
San Andreas (Mendocino Coast to San Benito County)	33%
Hayward	28%
Calaveras	24%
Hunting Creek, Berryessa, Green Valley, Concord	24%
Maacama	23%
Rodgers Creek	15%
San Gregorio	5%
Greenville	6%
Mt. Diablo	3%
West Napa	2%

<sup>1</sup>Source: *Uniform Earthquake Rupture Forecast, Version 3 (2014)*

## Surface Fault Rupture

A fault is a point of displacement along the fractures of the earth's crust caused by shifting tectonic plates. Active faults are those that have ruptured in the past 11,000 years. Often the rupture occurs deep within the earth, but it is possible for the rupture to extend to the surface and create visible above-ground displacement, called "surface rupture." The California Geological Survey (CGS) publishes maps of active Bay Area faults that could produce surface rupture, as required by the Alquist-Priolo Earthquake Fault Zoning Act (1972). These maps show the most comprehensive depiction of fault traces that can rupture the surface, and the zones directly above and surrounding the fault traces. Cities and counties require special geologic studies within these zones to prevent construction of human-occupied structures. For buildings already in these zones, the surface rupture hazard must be disclosed in real estate transactions.

Surface fault rupture varies in size and can change over time. Generally, a large magnitude earthquake can generate a longer rupture and greater displacement, though the surface expression of the displacement can vary widely. The M6.0 2014 South Napa Earthquake resulted in over one foot of displacement in some locations, while the M6.9 1989 Loma Prieta Earthquake had no surface fault rupture. In the 1906 Earthquake along the San Andreas Fault, surface rupture displacements were greater than 20 feet in some locations. Additionally, though the majority of displacement occurs during the actual earthquake event (called "co-seismic slip"), surface displacement can occur in the days, weeks, and even months after the event (called "post-seismic slip"). This was also observed in Napa and can cause additional damage for up to a year after an earthquake. In a large earthquake on the Hayward Fault the fault rupture displacement could reach 8 feet in some areas. Most of the displacement would occur during the shaking, and in the first day following the earthquake, but as much as 20 percent of the total afterslip could occur in the time between one month and 12 months after the quake, with the fault continuing to displace a full year after the earthquake.

## Ground Shaking

When faults rupture, the slip generates vibrations or waves in the earth that are felt as ground shaking. Larger magnitude earthquakes generally cause a larger area of ground to shake, and to shake more intensely. As a result, one principal factor in determining anticipated levels of shaking hazard in any given location is the magnitude of expected earthquakes. The intensity of ground shaking felt in one area versus another, however, is based on the magnitude and other factors including distance to the fault; direction of rupture; and, the type of geologic materials at the site. For example, softer soils tend to amplify ground shaking, while more dense materials limit ground shaking impacts at the site surface.

Ground shaking is commonly characterized using the Modified Mercalli Intensity (MMI) scale, which illustrates the intensity of ground shaking at a

**TABLE 3** MMI Intensity Table

Intensity	Building Contents	Masonry Buildings	Multi-Family Wood-Frame Buildings	1 & 2 Story Wood-Frame Buildings
MMI 6	Some things thrown from shelves, pictures shifted, water thrown from pools.	Some walls and parapets of poorly constructed buildings crack.	Some drywall cracks.	Some chimneys are damaged, some drywall cracks. Some slab foundations, patios, and garage floors slightly crack.
MMI 7	Many things thrown from walls and shelves. Furniture is shifted.	Poorly constructed buildings are damaged and some well-constructed buildings crack. Cornices and unbraced parapets fall.	Plaster cracks, particularly at inside corners of buildings. Some soft-story buildings strain at the first floor level. Some partitions deform.	Many chimneys are broken and some collapse, damaging roofs, interiors, and porches. Weak foundations can be damaged.
MMI 8	Nearly everything thrown down from shelves, cabinets, and walls. Furniture overturned.	Poorly constructed buildings suffer partial or full collapse. Some well-constructed buildings are damaged. Unreinforced walls fall.	Soft-story buildings are displaced out of plumb and partially collapse. Loose partition walls are damaged and may fail. Some pipes break.	Houses shift if they are not bolted to the foundation, or are displaced and partially collapse if cripple walls are not braced. Structural elements such as beams, joists, and foundations are damaged. Some pipes break.
MMI 9	Only very well anchored contents remain in place.	Poorly constructed buildings collapse. Well-constructed buildings are heavily damaged. Retrofitted buildings damaged.	Soft-story buildings partially or completely collapse. Some well-constructed buildings are damaged.	Poorly constructed buildings are heavily damaged, some partially collapse. Some well-constructed buildings are damaged.
MMI 10	Only very well anchored contents remain in place.	Retrofitted buildings are heavily damaged, and some partially collapse.	Many well-constructed buildings are damaged.	Well-constructed buildings are damaged.

ABAG, (2013). *Modified Mercalli Intensity Scale*

particular location by considering the effects on people, objects, and buildings. The MMI scale describes shaking intensity on a scale of 1-12. MMI values less than 5 don't typically cause significant damage; MMI values greater than 10 have not been recorded.

As described, a number of different faults contribute to the seismic hazard in the Bay Area. ABAG and the USGS worked collaboratively to characterize which fault contributes most to an area's seismic hazard. Figure 3 maps which fault contributes most to an area's seismic risk, taking into account the location's proximity to various faults, and the likelihood and severity of each fault. The map characterizes the fault with the greatest hazard, but many locations in the region can be severely impacted by multiple faults.

### ***Earthquake Shaking Scenarios***

ABAG and the USGS have developed several shaking scenario maps that depict shaking intensity for specific, plausible earthquake scenarios with a given magnitude on a fault. These maps show possible levels of ground shaking throughout the Bay Area in a single likely earthquake, taking into consideration the earthquake magnitude; rupture location and direction; and soil conditions throughout the region. Sixteen scenarios that could cause strong shaking in the Bay Area can be seen side-by-side in Figure 4. Mapping files can be downloaded for each scenario on the ABAG Resilience Program's online Open Data Page.

Scenario maps are helpful to model the expected shaking of an individual event, but they do not depict the likelihood of the event occurring or whether it is the most significant event for a particular location. A Probabilistic Seismic Hazard Assessment (PSHA) Map incorporates the likelihood of ground shaking from all nearby fault sources, and accounts for the frequency of each event. The PSHA Map in Figure 5 illustrates the 10 percent or greater chance in a 50 year period that each location on the map will exceed the MMI shown at least once.

In terms of risk characterization, it is equivalent to a 500-year flood. A 10 percent in 50 years hazard

level was chosen as it most closely aligns to the levels of shaking used in the current building code. Seismic hazard maps are not intended to be site-specific but depict the general risk within neighborhoods and the relative risk from community to community.

Events with strong shaking can still occur in areas with low probabilities shown in a PSHA map. The area damaged by the 2014 South Napa Earthquake is one example of a strong earthquake occurring in a location with lower risk probability than other areas within the region.

### **Liquefaction**

Soil that is loose, sandy, silty, and saturated with water can result in soil liquefaction if it is shaken intensely for an extended period. When ground liquefies in an earthquake, it behaves like a liquid and may sink, spread, or erupt in sand boils. This can cause pipes to break, roads and airport runways to buckle, and building foundations to be damaged. Liquefaction can only occur under certain circumstances:

- **Loose Soils** – The soils must be loose, such as uncompacted or unconsolidated sand and silt without much clay. This happens most often in the Bay Area along the Bay shoreline, near creeks or other waterways, on dry creek beds, and in areas of man-made fill, such as the Marina District in San Francisco or parts of Alameda.
- **Soggy Soils** – The sand and silt must be soggy and saturated with water due to a high water table.
- **Ground Shaking** – The ground must be shaken long and hard enough by the earthquake to trigger liquefaction.

Liquefaction may not necessarily occur even if all three conditions are present. Additionally, if liquefaction does occur, the ground may not move enough to have significant impact on the built environment. As with ground shaking, several types of maps depict liquefaction potential.

Liquefaction susceptibility maps show areas with soil types known to have the potential to

**FIGURE 3** Scenario Earthquake with Greatest Contribution to Area's Seismic Hazard

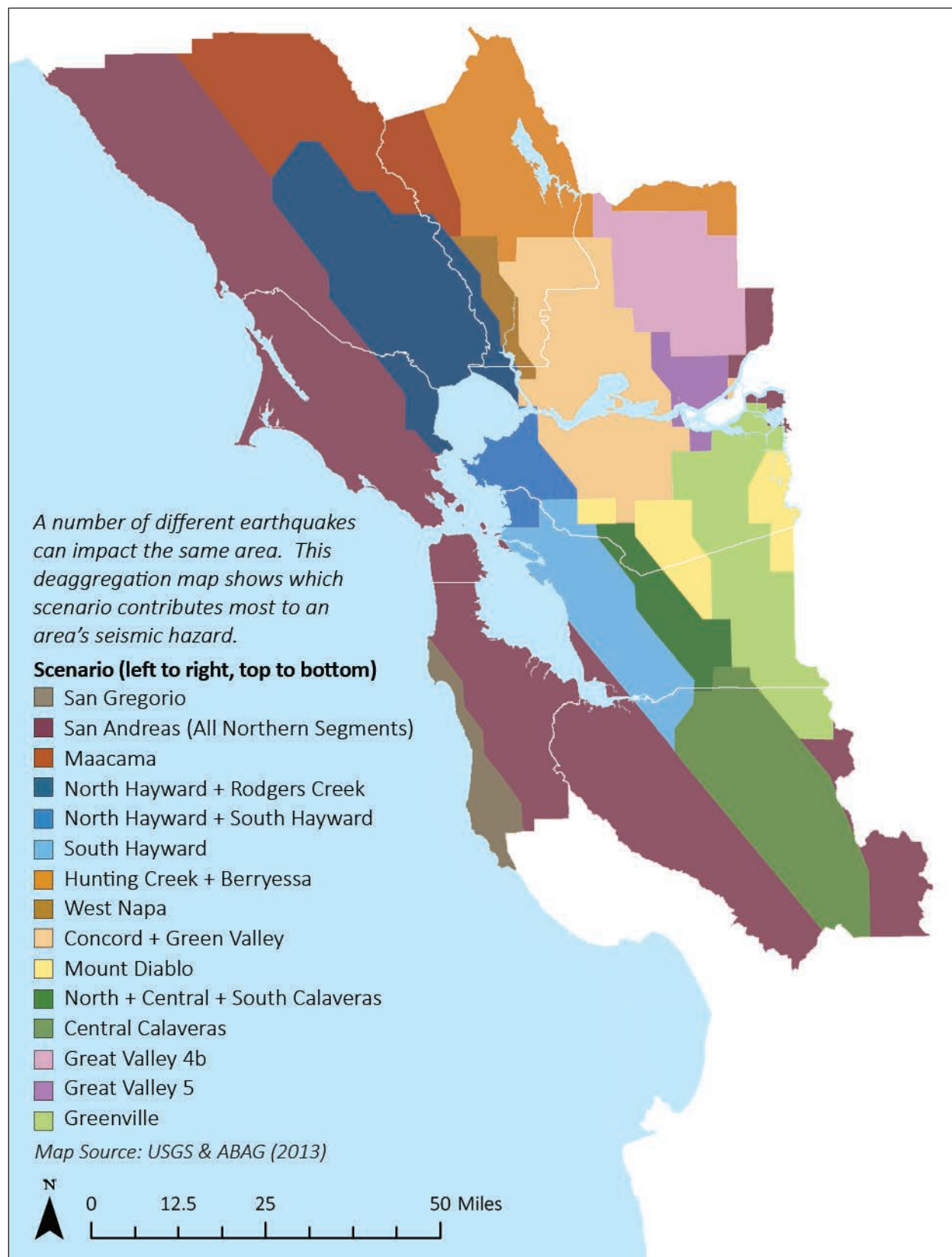


FIGURE 4 Scenario Earthquakes (page 1 of 2)

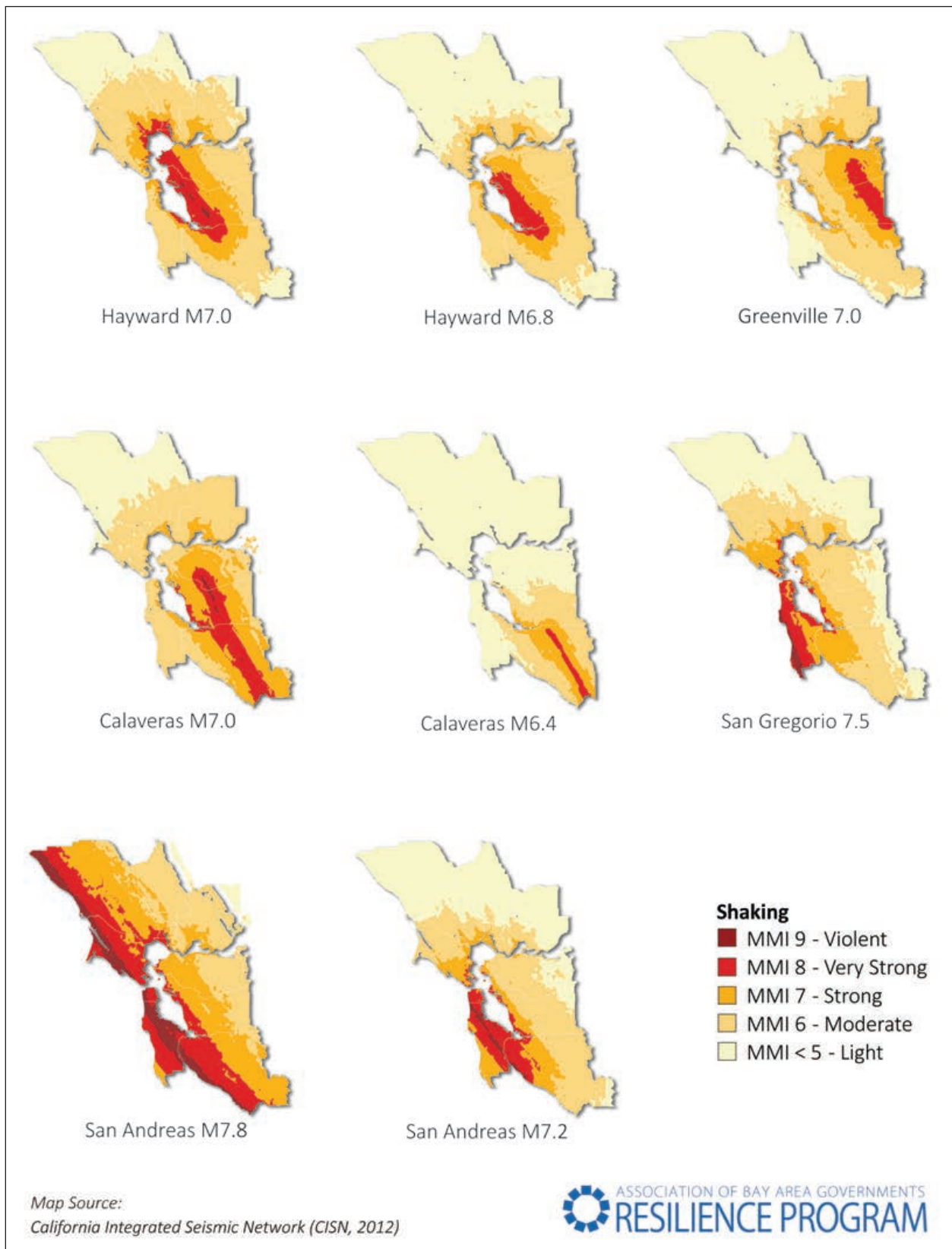
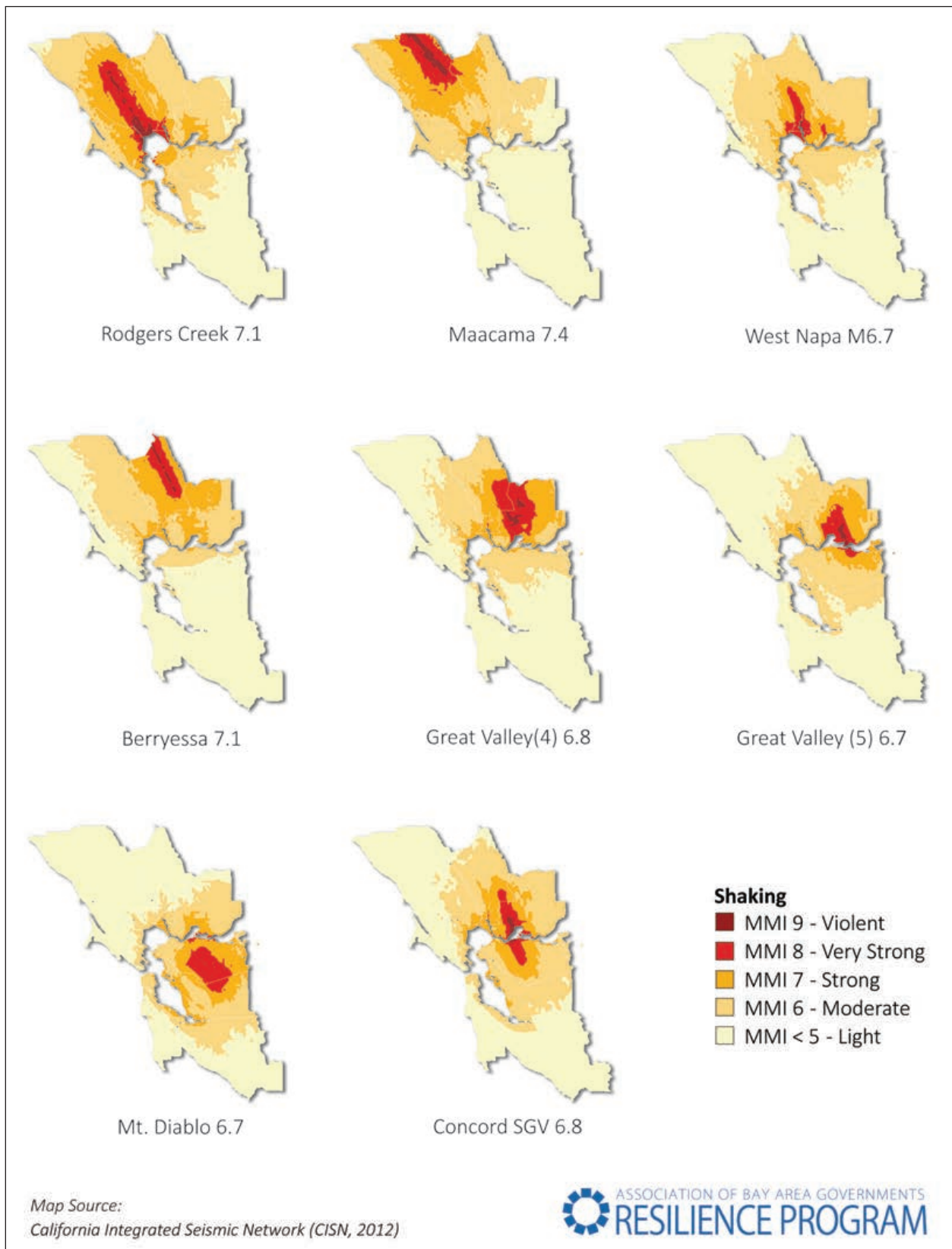
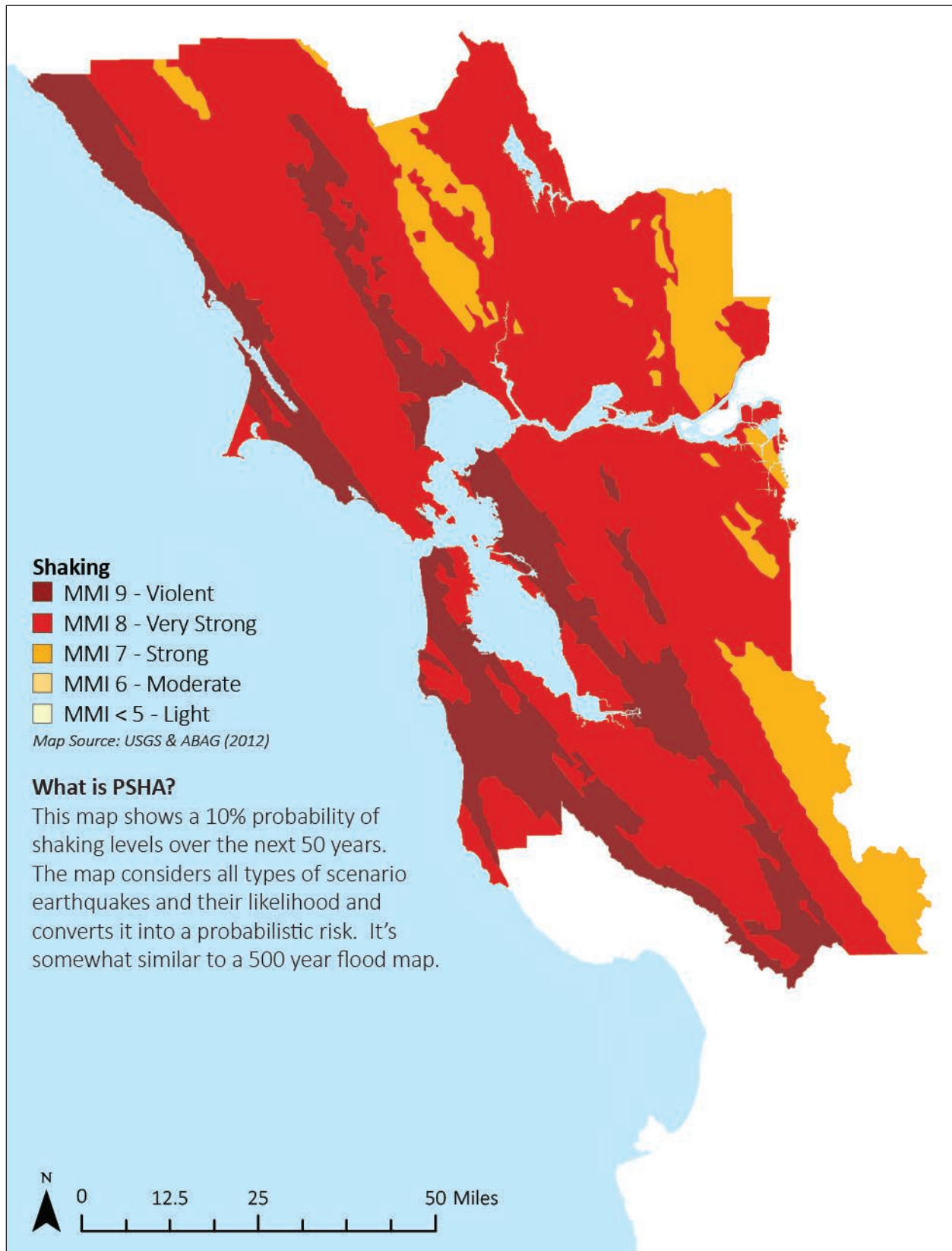


FIGURE 4 (continued) Scenario Earthquakes (page 2 of 2)



**FIGURE 5** Probabilistic Seismic Hazard Map (PSHA)



liquefy with intense shaking. Figure 6 shows maps illustrating liquefaction susceptibility for the entire Bay Area based on USGS soil type maps. However, site-specific investigations are needed to confirm liquefaction susceptibility on any given site.

Unless areas of liquefaction susceptibility are subject to significant ground shaking, they are not likely to liquefy. Liquefaction hazard maps express where the ground is both susceptible to liquefaction, and where the ground is likely to be shaken long and intensely in an earthquake. In 2015, ABAG produced maps that combine liquefaction susceptibility with USGS-generated earthquake scenarios to identify areas where there is a significant liquefaction hazard. Figure 7 is a representative example of the liquefaction potential in a M7.0 Hayward earthquake. The map combines the liquefaction susceptibility and Hayward shaking information into a scenario-based liquefaction potential map. These maps are available for all ground shaking scenarios shown in Figure 4. In some areas, USGS has done site-specific investigation to determine the approximate percent of the area that is predicted to liquefy in a M 7.1 earthquake on the Hayward Fault. These maps are available for Northwestern Alameda County and Northern Santa Clara County.

Additionally, Figure 8 is a map of Liquefaction Hazard Zone of Required Investigation for some portions of the Bay Area (Alameda, San Francisco, and Santa Clara Counties). This map is produced by CGS as part of its mapping program mandated by the Seismic Hazards Mapping Act. The CGS liquefaction zone maps are based on the presence of shallow historic groundwater in uncompacted sands and silts deposited during the last 15,000 years and sufficiently strong levels of earthquake shaking expected during the next 50 years. Like the fault zone maps, these official seismic hazard map zones require real estate disclosure upon point-of-sale and hazard analysis for new development. The CGS is continually working to expand the areas where their map is available and is currently mapping areas in San Mateo and Contra Costa County.

For more detailed information on liquefaction, ABAG's Real Dirt on Liquefaction provides

extensive information on the hazard. The maps produced in the 2001 report were updated by ABAG in 2015.

### Earthquake-Induced Landslides

Ground shaking can also lead to ground failure on slopes, triggering earthquake-induced landslides. Landslides tend to occur in weak soil and rock on sloping terrain. In the Loma Prieta earthquake, earthquake-induced landslides disrupted traffic for a month along Highway 17 in the Santa Cruz Mountains. In the Bay Area, the CGS has mapped areas of various risks for earthquake-induced landslide as part of its Seismic Hazards Zonation Program. Earthquake-induced landslide is discussed and mapped in greater detail in the landslide section on page XX.

### Tsunamis & Seiches

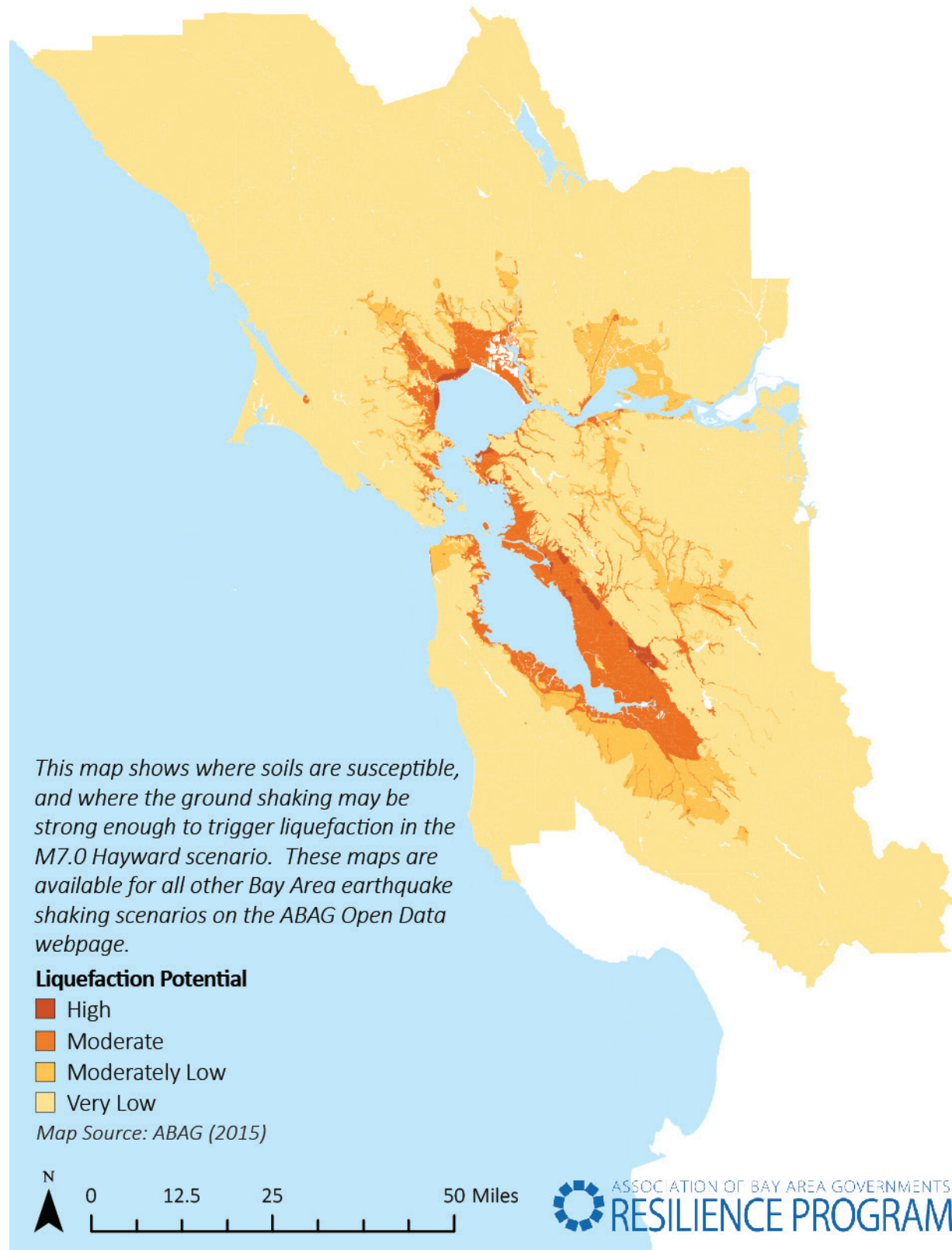
Large underwater displacements from major underwater earthquake fault ruptures or landslides can lead to ocean waves called "tsunamis." Since tsunamis have high velocities, the damage from a particular level of inundation is far greater than in a normal flood event. Similarly, water sloshing in a lake during an earthquake, called "seiche," is also capable of producing damage.

Tsunamis can result from off-shore earthquakes within the Bay Area or from distant events. It is most common for tsunamis to be generated by offshore subduction faults such as those in the Pacific Northwest, Alaska, Japan, and South America. Tsunami waves generated at those far-off sites travel across the ocean and reach the California coast with several hours of warning time. Local tsunamis can also be generated from offshore strike-slip faults. Because of their close proximity, we would have little warning time. However, the Bay Area faults that pass through portions of the Pacific coastline or under portions of the Bay are not likely to produce significant tsunamis because they move side to side, rather than up and down, which is the displacement needed to create significant tsunamis. They may have slight vertical displacements, or could cause

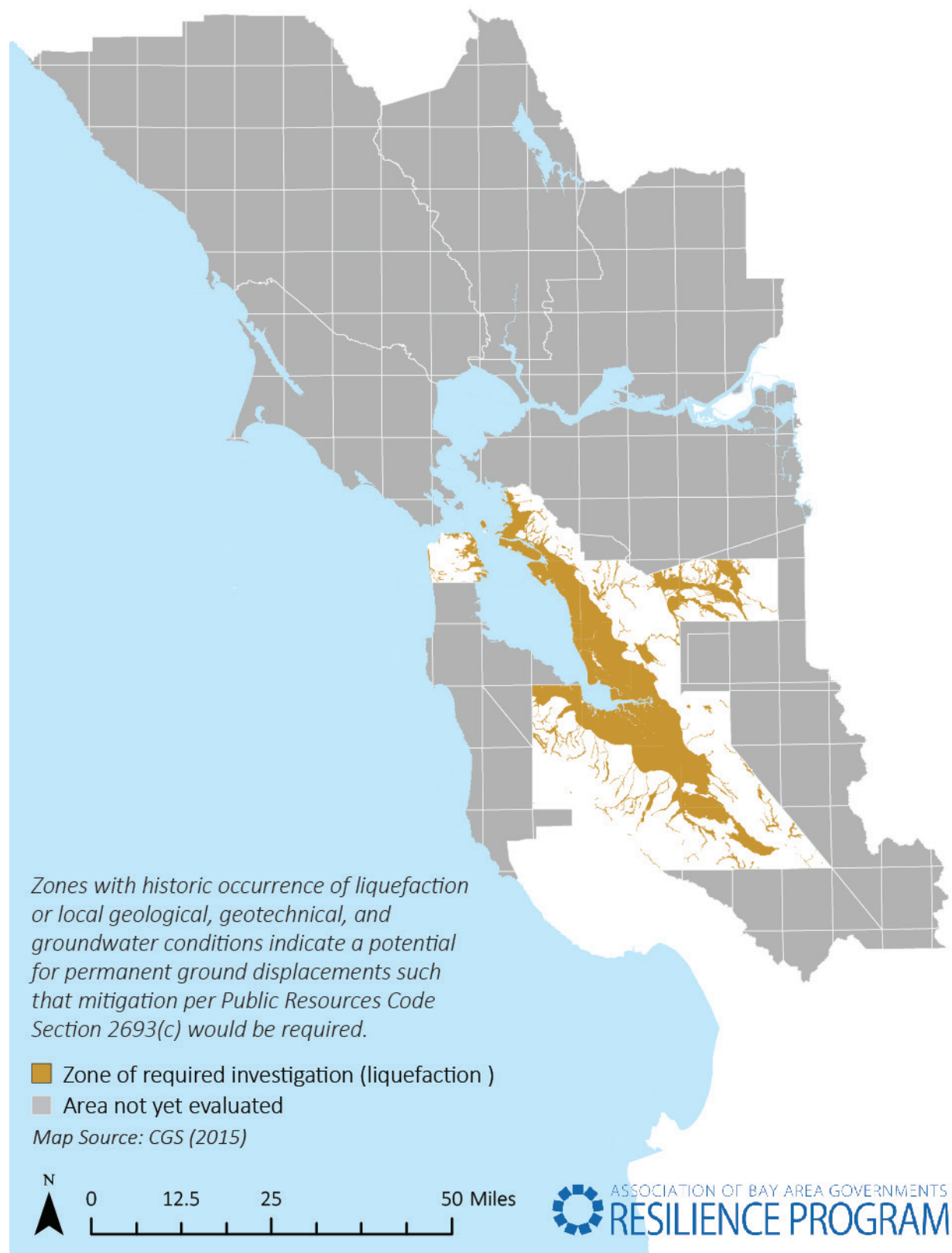
**FIGURE 6** Earthquake Liquefaction Susceptibility



**FIGURE 7** Scenario-based Liquefaction Potential Map – M7.0 Hayward



**FIGURE 8** Zones of Required Investigation - Liquefaction



small underwater landslides, but overall there is a minimal risk of any significant tsunami occurring in the Bay Area from a local fault. The greatest risk to the Bay Area is from tsunamis generated by earthquakes elsewhere in the Pacific.

Though the Bay Area has experienced tsunamis, it has not experienced significant tsunami damage. In 1859, a tsunami generated by an earthquake in Northern California generated 4.6 m wave heights near Half Moon Bay. The M6.8 1868 earthquake on the Hayward fault is reported to have created a local tsunami in the San Francisco Bay. In 1960, California experienced high water resulting from a magnitude 9.5 off the coast of Chile. The tsunami generated by the 1964 Alaskan earthquake caused wave heights of up to 1.1 meters along the coasts of San Francisco, Marin and Sonoma Counties. The 2011 tsunami created by the M9.0 Tohoku earthquake did not cause damage inside the Bay, but did cause damage to marinas and ports in both Santa Cruz and Crescent City. California has been fortunate in past distant-source tsunamis (1960, 1964, and 2011) that the events occurred during low tides.

In 2013, the USGS, in partnership with the California Geological Survey, the California Governor's Office of Emergency Services, NOAA, and other agencies and institutions, published a tsunami scenario as part of the Science Application for Risk Reduction (SAFRR) series. In the scenario, the multi-disciplinary team modeled a M9.1 offshore Alaskan earthquake to study impacts to California (Figure 9). Assuming that the tsunami reaches the central coast at high tide, the Bay Area can expect heights ranging from two to seven meters near the shore. Using an aggregate of tsunami sources from around the Pacific Ocean, waves with the same or larger amplitude as those in the tsunami scenario would occur, on average, every few hundred years.

In addition to the scenario inundation maps, CalOES developed tsunami evacuation maps indicating areas that should evacuate if a warning is given (Figure 10). The CalOES tsunami maps are not associated with a particular event but instead represent the worst-case scenario at any given location by combining a suite of extreme,

but plausible, inundation scenarios. Additionally, the maps include no information about the probability of a tsunami affecting an area at any given time. Because of this, it is not intended to show locations of probable inundation but should be used for evacuation planning only. In general, the CalOES tsunami evacuation map is more conservative than the USGS SAFRR study; however, there are a few locations where the SAFRR study shows greater inundation.

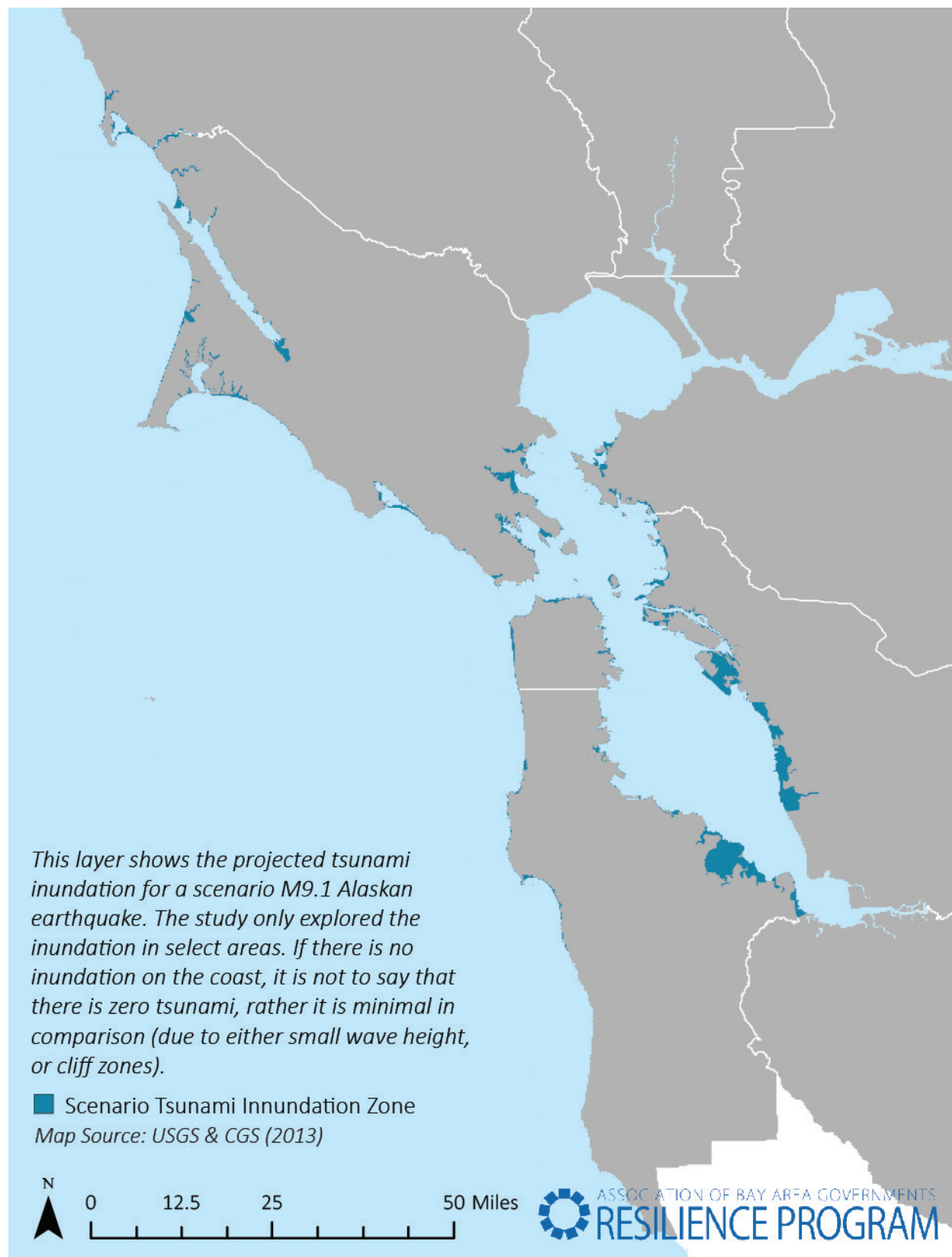
### Fire Following Earthquake

Earthquakes are often responsible for igniting fires which can contribute to a considerable share of the overall damage in a disaster. The fires can start from a variety of sources: appliances with natural gas pilot lights may tip, damaged electrical equipment may spark, and gas line connections may break. Recently in the South Napa Earthquake a number of mobile homes were destroyed and damaged when the gas connection to a home broke. In the Loma Prieta Earthquake 36 fires broke out in San Francisco alone, but luckily were contained quickly in large part due to the abnormally calm wind that evening, and the fires proximity to the bay which allowed a fire boat to pump water to the fire where the water lines had failed. In the 1906 earthquake over 3.5 square miles of San Francisco burned, representing 80% of San Francisco's property value at the time.

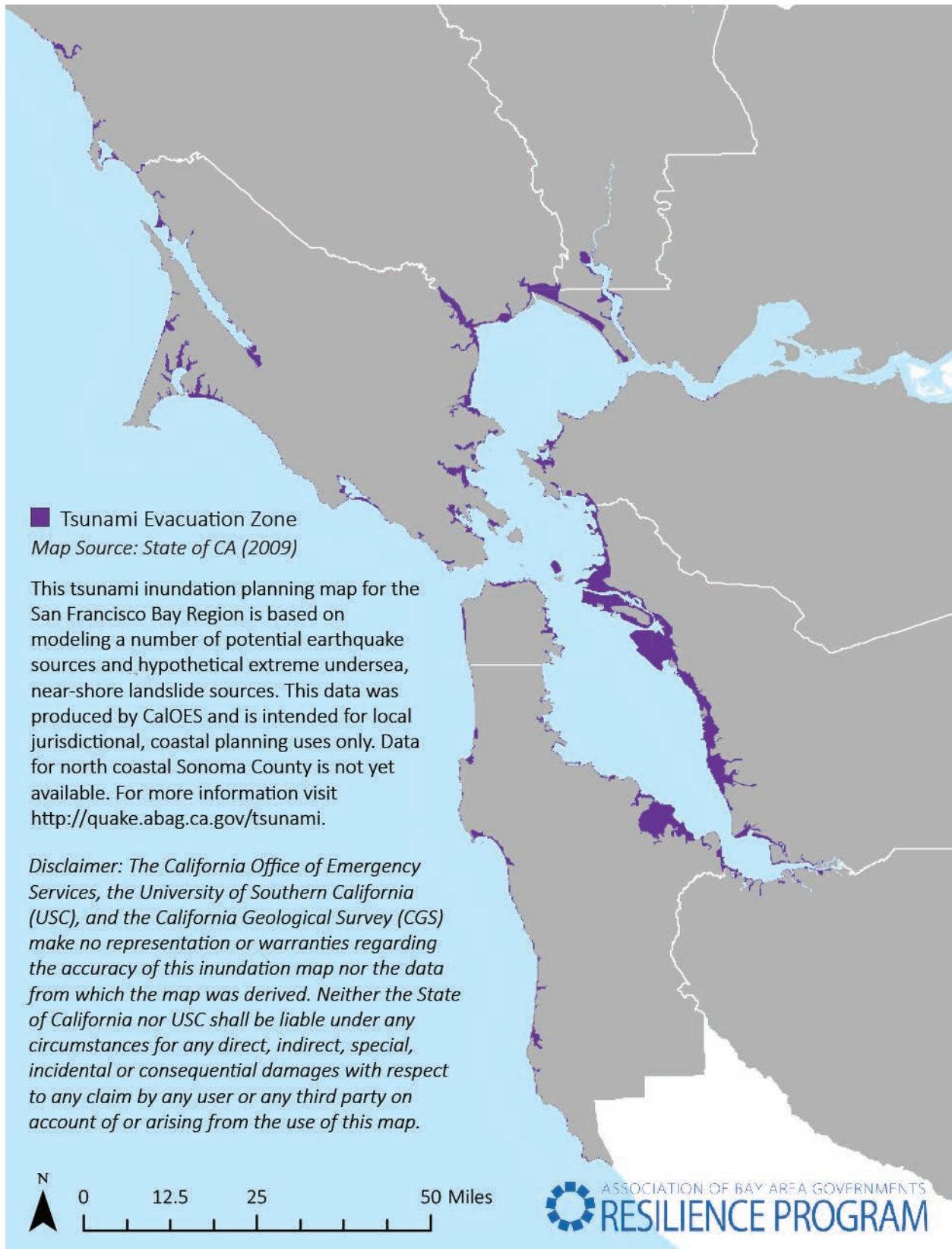
Fire following earthquake is especially challenging because there are often multiple ignitions at once (overwhelming fire crews), typical water supply for fighting fire may be reduced or unavailable (caused by ruptured water mains), and maneuvering fire crews to the ignition can be difficult if streets are blocked by road damage or by debris that blocks the streets. Fire following earthquake is an issue that could impact any Bay Area community that experiences an earthquake – both urban and rural. The problem is heightened for urban environments, where many simultaneous ignitions can lead to a firestorm, and single fires can more quickly and easily move structure to structure.

A few characteristics can make a specific community more vulnerable to fire following earthquake. If there is a higher likelihood of

**FIGURE 9** Scenario Tsunami from a M9.1 Alaska Earthquake



**FIGURE 10** Tsunami Inundation Emergency Planning Map



building damage, there is also a higher likelihood that an ignition occurs. If a building collapses there is a high risk for gas or electrical lines to start “seed” fires that then impact undamaged neighboring structures. Areas of liquefaction are more vulnerable to fire because of the greater potential for underground gas mains to break due to the ground displacements, and because the water lines in the area may also be damaged – preventing the ability to fight a fire with regular water resources. Areas that are largely wood frame or shingle roof may be less prone to earthquake damage, but are a heightened risk for the spread of fires. There is added concern in areas with hazardous materials because of the potential for explosion, fires, or toxic smoke. Industrial facilities and labs are a high concern because of the hazardous and flammable materials they store at their facilities.

## Landslide

In the Bay Area landslides typically occur as a result of either earthquakes (earthquake-induced landslides), or during heavy and sustained rainfall events. A given area can be at risk for both earthquake-induced landslides as well as landslides caused by rain-saturated soils but the variables that contribute to each landslide risk are different. Typically an earthquake-induced landslide occurs when seismic energy at the top of a slope gets concentrated and breaks off shallow portions of rock. In rainfall-induced landslides, the slide can begin much deeper in the slope, in very-saturated layers of soil.

For both types of landslides, there are not currently methods available to estimate the probabilities of future landslides at a local, or jurisdictional, scale. Steep slopes and varied types of underlying soils can influence the likelihood of landslides. Additionally, surface and subsurface drainage patterns also affect landslide hazard, and vegetation removal can increase landslide likelihood. Future landslides are most likely to occur within and around the places where they have previously occurred.

## Historic Bay Area Landslide Occurrences

Flooding and landslides associated with severe storms have been among the most common disasters in the Bay Area during the period from 1950 to 2009. Extensive landslides have occurred 24 times since 1950, approximately once every three years.

Losses from landslides are typically lower than those from associated flooding. However, in the El Nino storms of early 1998, USGS documented approximately \$150 million in losses due to approximately 300 landslides of varying sizes that occurred in the Bay Area and Santa Cruz County. The greatest number of landslides in the region since 1950 occurred in 1982, when a large storm event preceded by a wet winter triggered over 18,000 landslides in the region, which resulted in 33 deaths and 481 injuries.

## Probability of Future Landslide – Climate Influenced

As described above, landslides are typically triggered by earthquakes or prolonged severe wet seasons. Climate change is not expected to change the seismic risk, but climate change could change the behavior of winter storms. The regional models project fairly similar precipitation totals in the Bay Area, but the variability season to season may increase. If winters are compressed, with more rain falling in fewer months, or if individual years are more extreme the chance of rainfall-induced landslide will increase. Additionally, if fires burn greater portions of landslide-vulnerable hillsides, removing vegetation and increasing storm runoff, the landslide probability will increase. The increase in future fire risk in the more mountainous regions of the Bay Area is described in the Fire section on page XX. Currently, there is not enough evidence to suggest with certainty that future landslide probabilities will increase across the region, however local studies that take local conditions into consideration may reveal the potential for greater landslide risks in the future.

## Landslide Hazard in the Bay Area

The CGS maps Earthquake Induced Landslide Study Zones (see Figure 11). The map designates zones in which a landslide study is required before the land can be developed, similar to CGS's Liquefaction Hazard Zone of Required Investigation (Figure 8). The CGS has only mapped portions of Alameda, San Francisco, and Santa Clara Counties. Portions of San Mateo and Contra Costa counties are currently being mapped. This CGS map only depicts earthquake induced landslide zones, not areas at risk of landslide from storm events.

Winter rain storms can impact hillsides by triggering fast-moving debris flows, or mudslides, and other slower-moving landslides. In general, landslides are most likely during periods of higher than average rainfall or El Nino winter storms. In addition, the ground must be saturated prior to the onset of a major storm for significant landsliding to occur. But there is currently no method to estimate the scale of individual landslides in terms of size or extent based on these maps, or to assign specific probabilities to these areas in terms of the likelihood of future landslides. The USGS developed a region-wide rainfall-induced landslide hazard map, shown in Figure 12. The map shows areas where rainfall-induced landslides have occurred in the past, as landslides are most likely to occur in and around areas where they have previously occurred.

## Flood

Flooding is a temporary condition that causes the partial or complete inundation of land that is normally dry. Flooding occurs when streams, rivers, lakes, reservoirs, or coastal water bodies are abnormally high and overflow into adjacent low-lying areas, areas at risk of recurring floods known as floodplains.

Coastal flooding is generally associated with Pacific Ocean storms from November through February when high tides coincide with strong winds both on the outer coast and within the Bay.

Riverine flooding, also known as overbank flooding, can occur if there is excessive rainfall especially in conjunction with high tides and strong winds. Riverine floodplains range from narrow, confined channels in the steep valleys of mountainous and hilly regions to wide, flat areas in plains and coastal regions. The potential for flooding of a floodplain is a function of the size and topography of the contributing watershed, the regional and local climate, and land use characteristics. Flooding in steep, mountainous areas is usually confined, occurs with less warning time, and has a short duration. Larger rivers typically have longer, more predictable flooding sequences and broad floodplains. The lower portion of coastal rivers are more likely to flood during high tides with backwater conditions that lead to overbank flooding.

Localized or nuisance flooding can occur in areas during heavy precipitation events, especially if ground water levels are high during extremely wet seasons or if stormwater storage or conveyance facilities are inadequate. Localized flooding tends to occur in flat, urbanized areas that are highly impermeable and can result in inundation of basements, low lying roads, and parking lots from street drainage.

## Historic Bay Area Flooding

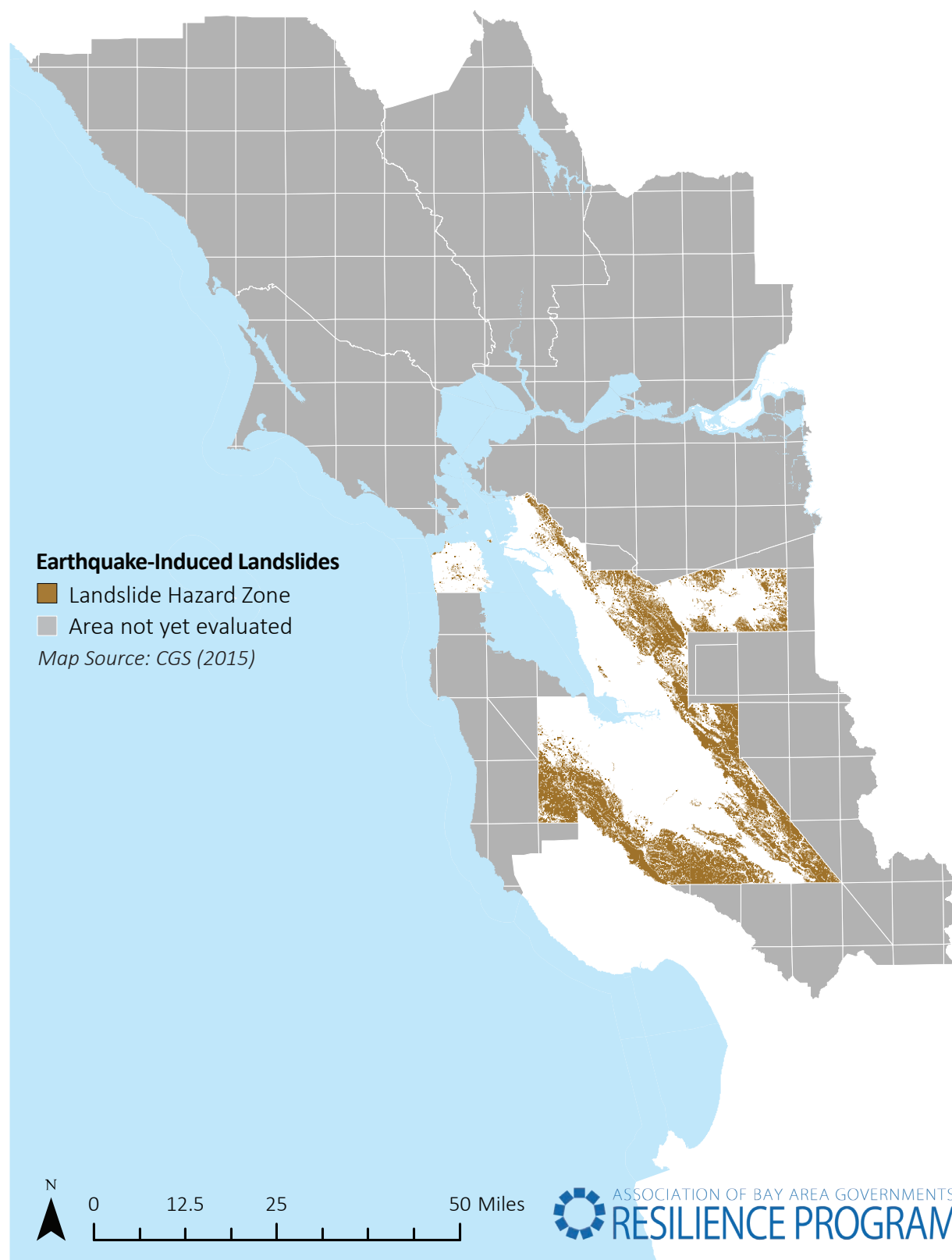
Flooding associated with severe storms has been among the most common disaster in the Bay Area during the period from 1950 to 2015, occurring nearly annually on average. Often heavy rainfall brings many areas of localized flooding, especially in low lying areas of the region. Many other locally significant floods have occurred during this time period.

Extensive flooding occurred in 1950, 1957, 1958, 1959, 1962, 1963, 1964, 1965, 1966, 1969, 1970, 1973, 1980, 1982, 1983, 1992, 1995, 1996, 1997, 1998, 2005, 2006, and 2008.

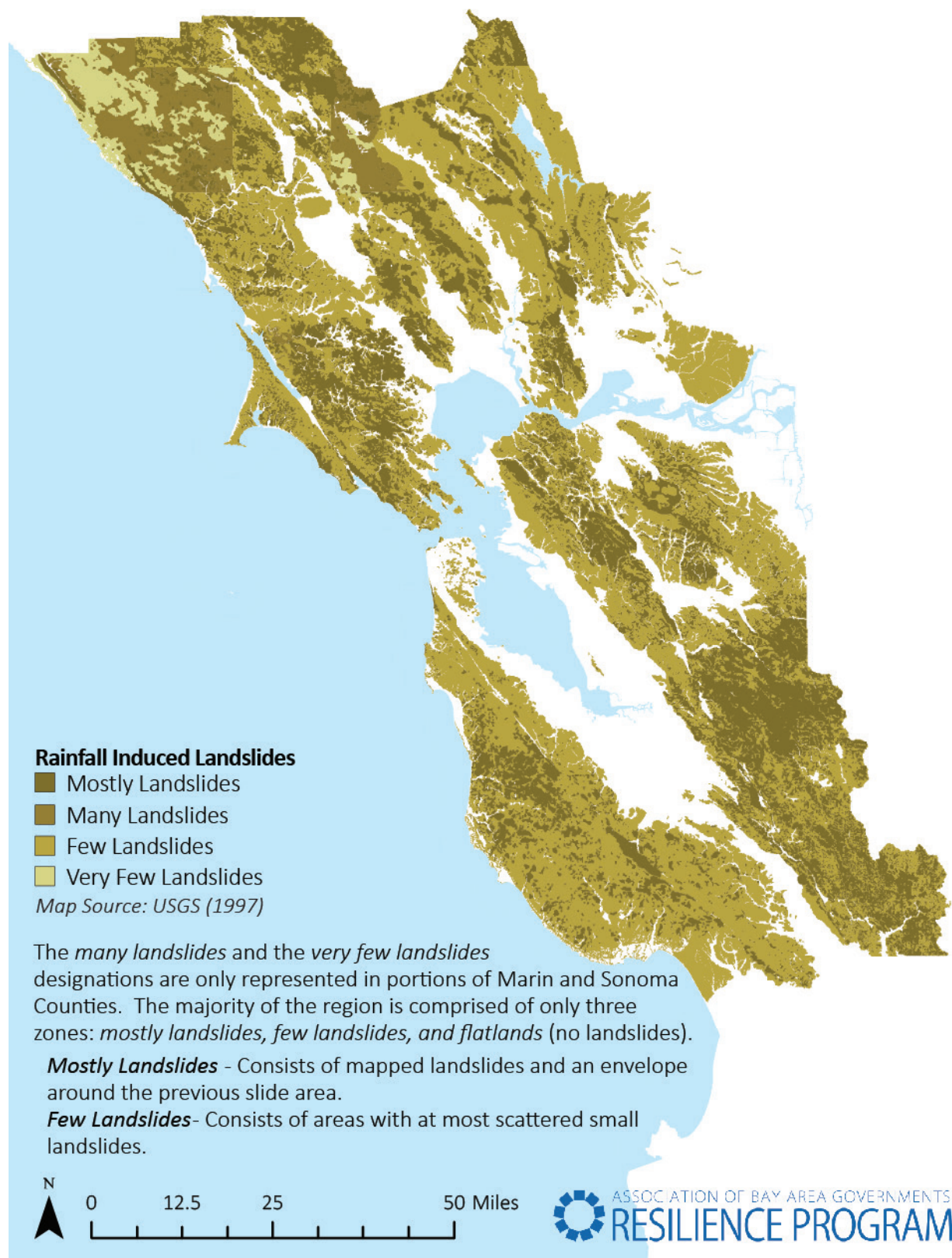
## Probability of Future Flooding

Globally, sea levels are rising due to thermal expansion caused by the ocean warming and the melting of land-based ice such as glaciers and

**FIGURE 11** Earthquake-Induced Landslide Hazard Zones



**FIGURE 12** Rainfall-Induced Landslides: Existing Landslides



polar ice caps. Regionally and locally, the rate of sea level rise is affected by other processes, including changes in land elevation (subsidence or uplift), coastal erosion, wind and ocean currents, ocean temperature and salinity, atmospheric pressure, and large-scale climate regimes.

The National Research Council (NRC) Sea-Level Rise for the Coasts of California, Oregon, and Washington study, released June 2012, provides regionally specific sea level rise projections for the Coasts of California, Oregon, and Washington. Because there is significant uncertainty in how much sea level will rise, the range in projected values increases over time.

Sea level rise has the potential to influence the impact of coastal, riverine and localized nuisance flooding. In particular, without intervention rising sea levels may cause:

#### More Frequent Floods

Rising sea levels can lead to more frequent flooding of existing flood-prone areas, including more frequent overtopping and overbank flooding of riverine systems that already flood when rainfall coincides with high tides due to the increased backwater effect. In addition, gravity drained and pumped systems that

discharge stormwater into flood control channels can have reduced performance, causing backups and flooding of streets and basements.

#### More extensive, longer-duration flooding

As sea levels rise there is the potential that storm events will flood larger areas for longer periods of time and that there will be new overtopping and overbank flooding of riverine systems that do not currently cause flooding.

#### Shoreline erosion and overtopping

Sea level rise can cause shoreline protection, such as levees, berms and revetments, to be damaged or fail to due to increased tidal and wave energy. There is also the potential that shoreline protection will be overtopped during storm events when there are extreme tide levels and wind-driven waves, flooding inland areas, including homes and community services that are currently protected.

#### Elevated groundwater and increased salinity intrusion

As sea levels rise, groundwater and salinity levels are also predicted to rise. This will

**TABLE 4 Regional Sea Level Rise Projections Relative to Year 2000 for the California Coast South of Cape Mendocino<sup>1</sup>**

Year	NRC 2012 Projection (mean ± the standard deviation for the A1B Scenario <sup>2</sup> )	Low (mean of the B1 scenario)	High (mean of the A1F1 scenario)
2030	5.6 (±1.9)	2	12
2050	11.0 (±3.6)	5	24
2100	36.1 (±10)	17	66

<sup>1</sup>Committee on Sea Level Rise in California, Oregon, and Washington, and Board on Earth Sciences and Resources and Ocean Studies Board, Division on Earth and Life Studies, (2012).

<sup>2</sup>The A1 scenario family assumes high economic growth, low population growth that peaks mid-century, and the rapid introduction of more efficient technologies (A1B is balanced and A1FI is fossil fuel intensive). The B1 scenario family assumes the same low population growth as the A1 scenarios, but a shift toward a lower-emission service and information economy and cleaner technologies.

cause damage to below grade living spaces, finished basements, and electrical/mechanical equipment that is below or at-grade. In addition, increasing groundwater levels may increase liquefaction susceptibility, and require the use of stormwater pumping for flood management, which will increase both operations and maintenance costs.

### Permanent Inundation

Sea level rise can cause areas that are not currently exposed to regular high tide inundation to be flooded, resulting in the need to either protect or move people and infrastructure, and the loss of trails, beaches, vistas, and other shoreline recreation areas. In addition, increased tidal scour due to increased tidal prism in riverine systems can trigger changes in channel geometry and sediment transport processes.

## Flood Hazard in the Bay Area

### Current Flooding

The magnitude of flood used as the standard for floodplain management in the United States is a flood having a probability of occurrence of one percent in any given year, also known as the 100-year flood or base flood. The most readily available source of information regarding the 100-year flood is the system of Flood Insurance Rate Maps (FIRMs) prepared by FEMA. These maps are used to support the National Flood Insurance Program (NFIP) and show 100-year floodplain boundaries for identified flood hazards. These areas are also referred to as Special Flood Hazard Areas (SFHAs) and are the basis for flood insurance and floodplain management requirements under the NFIP. FIRMs also show floodplain boundaries for the 500-year flood, which is the flood having a 0.2 percent chance of occurrence in any given year (see Figure 13).

The rivers and streams for which FEMA has prepared detailed engineering studies may also have designated floodways. The floodway is the channel of a watercourse and portion of the adjacent floodplain that is needed to convey the

base or 100-year flood event without increasing flood levels by more than 1 foot and without significantly increasing flood velocities. The floodway must be kept free of development or other encroachments.

Existing coastal and riverine flood maps are available from FEMA, and include existing and preliminary map products for the San Francisco Bay and the Outer Coast of California.

The following factors contribute to the frequency and severity of **coastal flooding**:

- Astronomical Tides
- Storm Surge
- Wind Waves
- El Nino Events
- Sea Level Rise

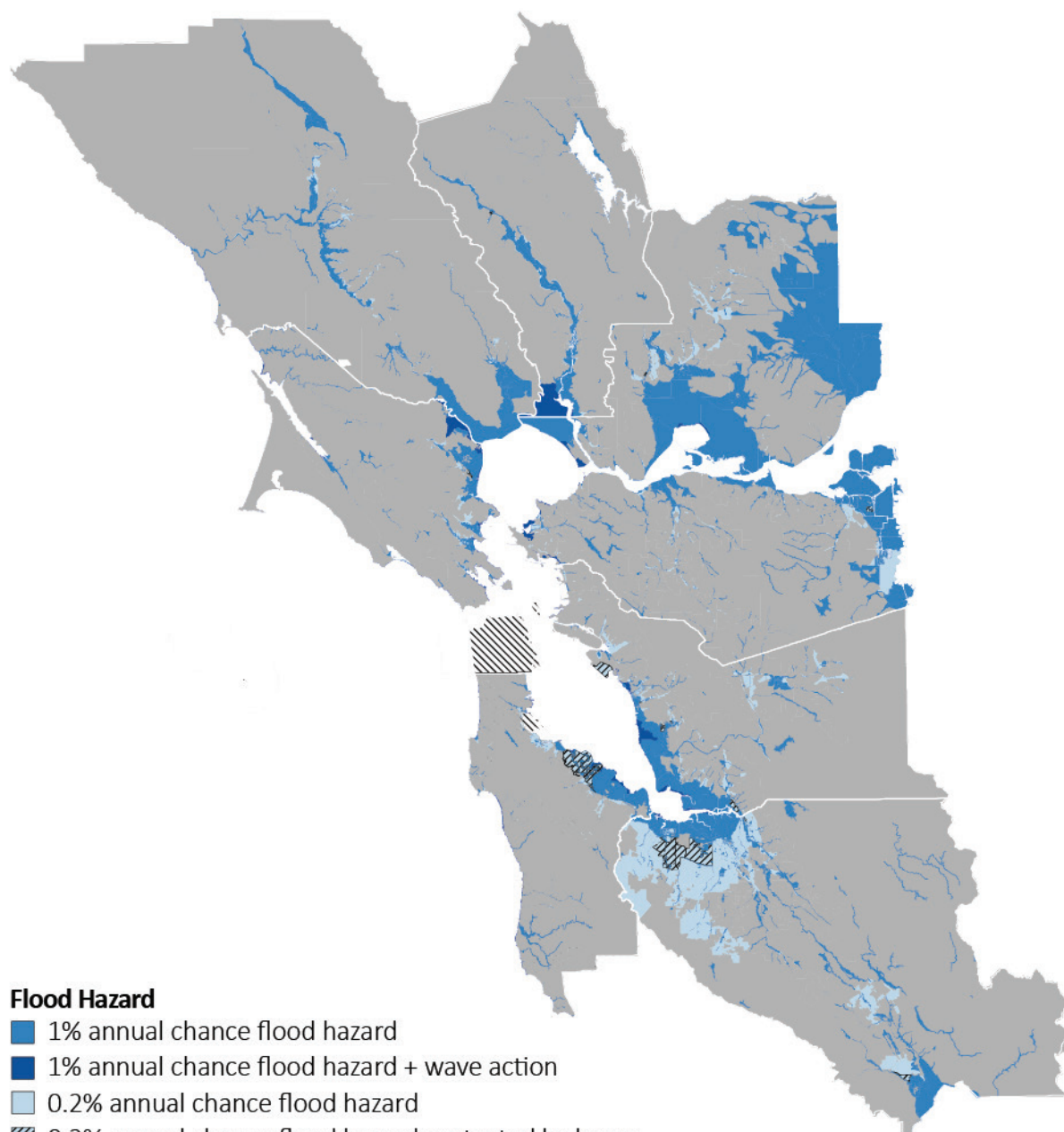
The following factors contribute to the frequency and severity of **riverine flooding**:

- Rainfall intensity and duration
- Antecedent moisture conditions
- Watershed conditions, including steepness of terrain, soil types, amount, and type of vegetation, and density of development
- The existence of attenuating features in the watershed, including natural features such as swamps and lakes and human-built features such as dams
- The existence of flood control features, such as levees and flood control channels
- Velocity of flow
- Availability of sediment for transport, and the erodibility of the bed and banks of the watercourse

### Future Flooding

In the Bay Area, the potential for new or prolonged flooding as sea level rises will not be confined to the shoreline. Sea level rise will increase the likelihood of major flood events around the Bay Area because higher water levels in tidal creeks and flood control channels will reduce capacity to discharge rainfall runoff. While some creeks

FIGURE 13 100 and 500 Year Floodplains



**Flood Hazard**

- 1% annual chance flood hazard
- 1% annual chance flood hazard + wave action
- 0.2% annual chance flood hazard
- 0.2% annual chance flood hazard protected by levee
- Not in the 1% or 0.2% annual chance flood hazard
- Area not mapped\*

Map Source: FEMA (2015)

\*A new map update for the City & County of San Francisco is expected in 2016.

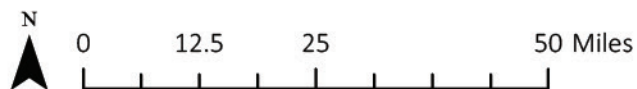
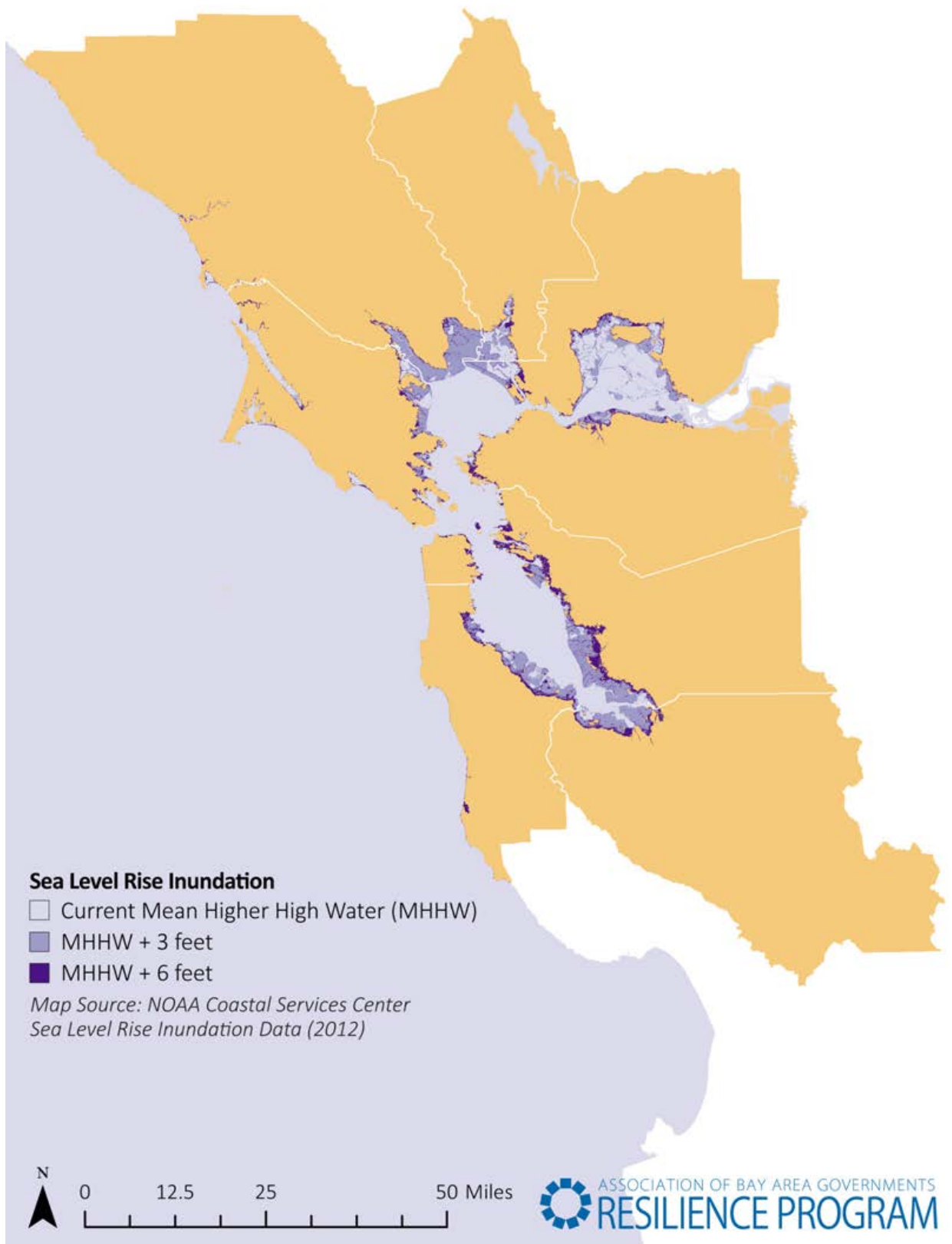


FIGURE 14 Sea Level Rise Innundation



already flood when rainstorms coincide with high tides, rising sea levels will cause more widespread flooding during smaller, more frequent rainfall events.

Sea level rise inundation maps (see Figure 14) help to visually assess under what conditions assets may be impacted by sea level rise and storm events and how far reaching the consequences may be if they are impacted. To understand these factors it is helpful to evaluate a range of possible future sea level rise scenarios. The “total water level” approach presented below simplifies this process and reduces the number of maps needed. In this approach each inundation map represents a number of different unique combinations of sea level rise and extreme tide (storm surge) conditions.

A total water level of 36 inches above mean higher high water (MHHW) can represent a new “daily” high tide with 36 inches of sea level rise. This amount of sea level rise, which is a likely projection for 2100, could result in regular and permanent tidal inundation. This total water level can also represent today’s 50-year extreme tide level, a one-year extreme tide level with 24 inches of sea level rise, or a five-year extreme tide level with 12 inches of sea level rise, which is a likely 2050 projection. Extreme tide events that are larger than daily high tide levels can result in episodic, short duration, or temporary, flooding.

The matrix of numbers presented in Table 4 can be used to understand a range of total water levels, from 0 to 95 inches above MHHW, represented both in terms of today’s tides and future tides as sea level rises. Each total water level represents a combination of sea level rise (0 to 60”) and tide levels (MHHW to a 100-year extreme event). As an example, the likely mid-century daily high tide is projected to be 12” above today’s high tide, or 12”+MHHW. This total water level is approximately the level observed during King Tide, which is an astronomical tides that occur approximately twice per year when the Moon and the Sun simultaneously exert their gravitational influence on the Earth.

Because of the uncertainties associated with modeling and mapping sea level rise it is reasonable to allow for a +/- 3-inch range when interpreting the total waters in Table 4. As an example, the likely end-century high tide is projected to be 36 inches above today’s high tide, or 36”+MHHW. Water levels ranging from 33 to 39 inches can be used to understand what other combination of tides and sea level rise that may result in the same amount of flooding or inundation as 36”+MHHW.

The values presented in Table 4 are generally applicable to central San Francisco Bay and are therefore appropriate for local and regional scale climate adaptation planning, although it may not be as precise for some areas of south and north Bay. In addition, because tide levels do vary around the Bay, additional information about tide levels should be used for site-scale planning. Finally, the values in Table 4 are based on an analysis that does not include the effects of locally wind waves and assumes that future storms will behave like past storms.

There are a number of online tools that provide regionally relevant sea level rise inundation maps. The most commonly used is the NOAA Sea Level Rise and Coastal Flooding Impacts Viewer. This is a national tool that depicts potential impacts to marshes and human communities from a range of sea level rise projections from zero to six feet coupled with mean higher high water (MHHW). It also illustrates changes in flood frequency and includes visual simulations of local site flooding.

## Fire

Fires are typically characterized into three categories: urban fires, wildland-urban interface fires, and wildland fires.

- Urban fires occur within a developed area and pose a direct risk to development.
- Wildland-urban interface (WUI) fires occur where the built environment and natural areas are intermixed (the fringe of urban areas).
- Wildland fires exist in wilderness land.

**TABLE 5** Matrix showing combinations of Sea Level Rise and Extreme Tide Level

		Total water level above today's daily high tide, MHHW (inches NAVD88), by tide recurrence interval							
Time Frame	Sea Level Rise	MHHW (= daily high tide)	1-yr (= king tide)	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr (1% annual chance)
Today		0	12	19	23	27	32	36	41
	+6	6	18	25	29	33	38	42	47
Likely Mid-Century	+12	12	24	31	35	39	44		53
	+18	18	30	37	41	45	50	54	59
	+24	24	36	43	47	51	56	60	65
	+30	30	42	49	53	57	62	66	71
Likely End-of-Century	+36	36	48	55	59	63	68	72	77
	+42	42	54	61	65	69	74	78	83
	+48	48	60	67	71	75	80	84	89

Map Scenario (inches above MHHW)	
48	High tide with 12" of sea level rise and 50yr storm <b>or</b> high tide with 48" of sea level rise.
36	High tide today w/ 100yr storm <b>or</b> high tide on regular day with 36" of sea level rise.
24	High tide today w/ 50yr storm <b>or</b> high tide on regular day with 24" of sea level rise.
12	High tide today w/ 1yr Storm <b>or</b> high tide on regular day with 12" of sea level rise.
MHHW	High tide today (MHHW).

Fires in the urban environment and in the wildland-urban interface result in direct damage to the built environment and can injure or kill residents. Wildland fires can cause damage to linear infrastructure systems that serve the Bay Area, causing outages downstream of the failure; can impact the air quality in cities during the duration of the fire; and can impact water quality in watersheds impacted by a wildland fire. Wildland and wildland-urban interface fires can also damage natural environments, such as recreational areas, and can cause lasting impacts to slopes and soils (see the landslide section on page XX on the relationship between fire and landslide).

In the Bay Area, fire areas generally fall into two categories – State Responsibility Areas, where CALFIRE is responsible for fire protection, and Local Responsibilities, where local fire departments and fire protection districts have responsibility.

## Historic Bay Area Fire Occurrences

Wildfires were common disasters in the Bay Area during the period from 1950 to 2014. Large wildfires occurred in 1961, 1962, 1964, 1965, 1970, 1981, 1985, 1988, 1991, and 2008. The 1991 fire in the Oakland-Berkeley Hills was the largest urban-wildland fire in the Bay Area, and resulted in \$1.7 billion in losses. In that fire, 3,354 single-family dwellings and 456 apartments were destroyed, while 25 people were killed and 150 people were injured. Despite the drought conditions locally over the past four years the Bay Area has had very few fires, and few large fires.

## Probability of Future Fire – Climate Influenced

Wildfire risk increases due to climate change because of higher temperatures and longer dry periods over a longer fire seasons. Additionally, wildfire risk will also be influenced by potential changes in vegetation.

Research out of UC Merced has projected the future fire risk, impacted by climate change, compared to existing fire risk. In the Bay Area the

results are mixed. The research projects some locations in the East Bay and South Bay to exhibit decreased fire risk, while areas on the Peninsula and North Bay exhibit a 150 percent increase in fire risk by 2085. Generally, across the Bay Area there is fairly limited change in fire risk in the year 2050, with the greatest change in occurring between 2050 and 2085, especially in the high emission climate change scenario. The Cal Adapt data suggests that some jurisdictions might have to adapt more aggressively compared to others. Figure 17 shows the projected fire risk increase for the Bay Area with the greatest increase and decrease areas highlighted.

The future fire risk model analyzes two primary variables: fuel availability and flammability of fuel. In California the change in fire risk is a result of either a densely forested ecosystem becoming drier, or a dry climate experiencing large vegetation growth after a year of above average precipitation. In the first scenario the suite of climate impacts (higher temperatures, less snow pack, earlier springs) result in previously wet dense fuel ecosystems becoming dry – increasing the fire risk. In the second ecosystem, dominated by grass and low density shrubs, the risk is often unchanged or decreased because the availability of fuel is the governing variable for fire risk, which remains unchanged or decreases as a result of projected precipitation. These modeling characteristics are reflected in the Bay Area's future fire risk map.

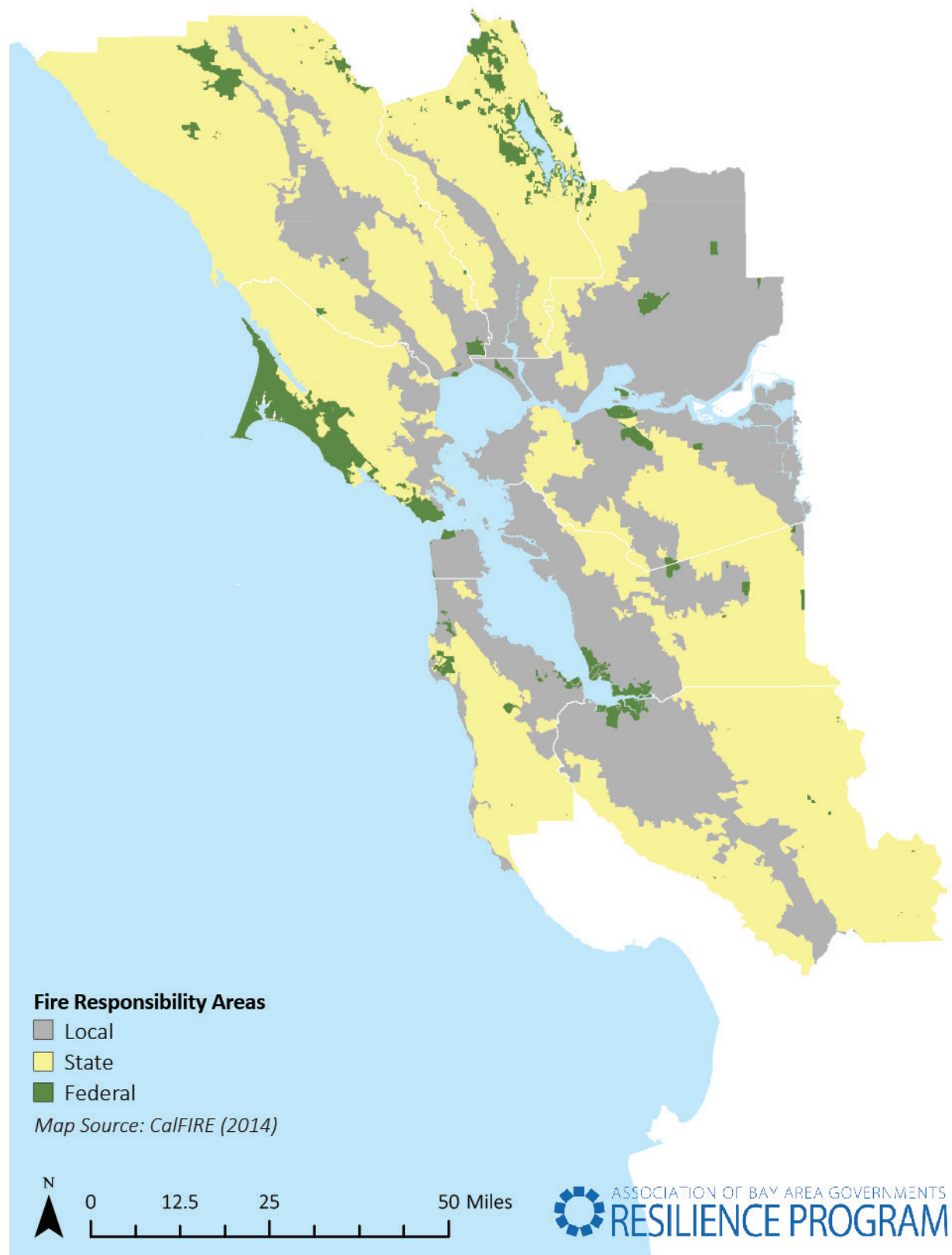
The Bay Area, compared with other portions of California, especially those near the Oregon border, have a much lower projected increase in fire risk due to climate change. Near the Oregon border, many areas are expecting a 500 percent increase in fire risk by 2085, with some areas projected to see their fire risk increase more than 10 times.

## Fire Hazard in the Bay Area

### Wildfire

CALFIRE has developed maps depicting wildfire hazard areas. Figure 18 is a map of fire hazard severity in State Responsibility Areas. Fire

**FIGURE 15** Fire Responsibility Areas



**FIGURE 16** Historic Bay Area Fire Perimeters

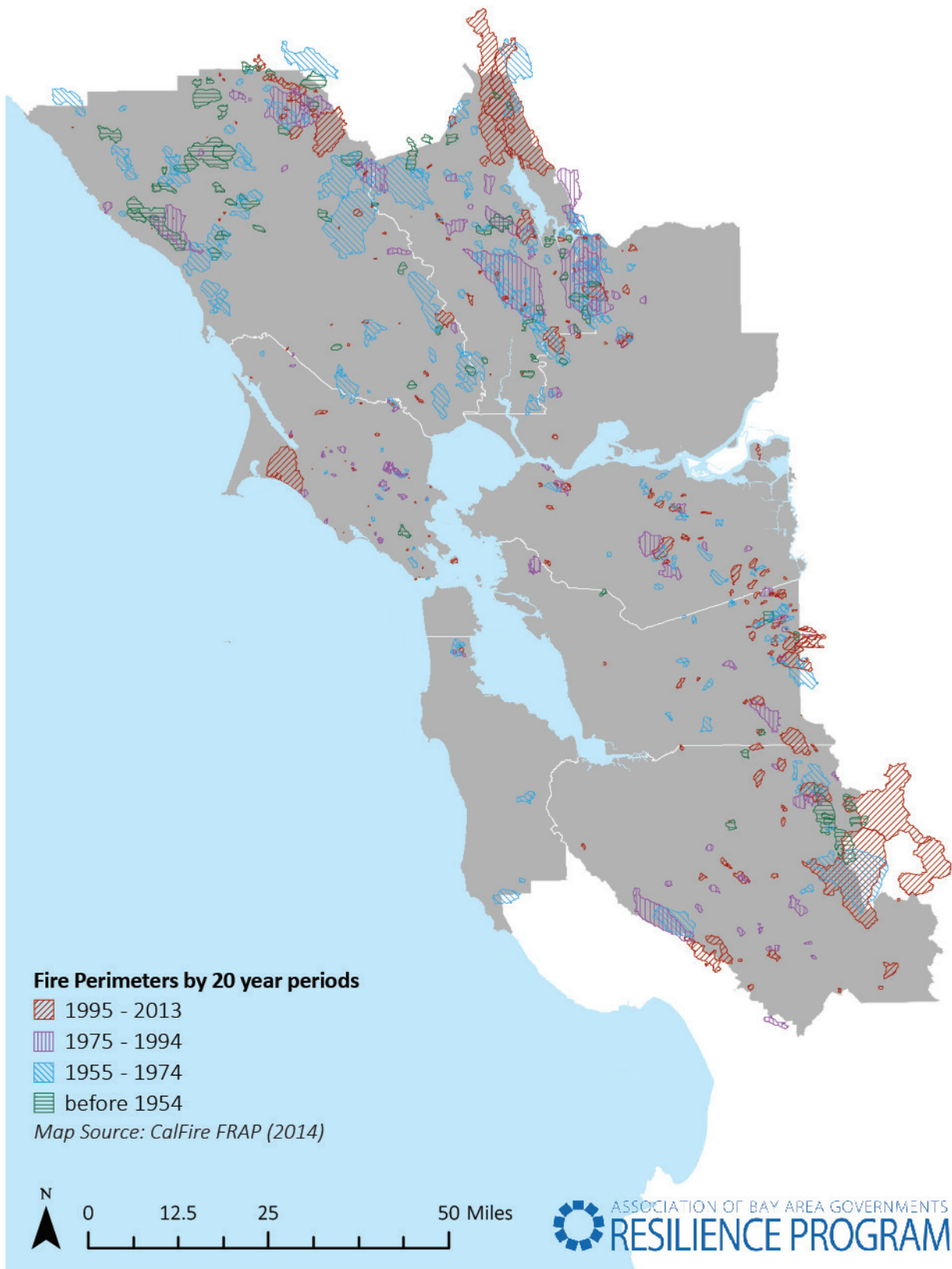
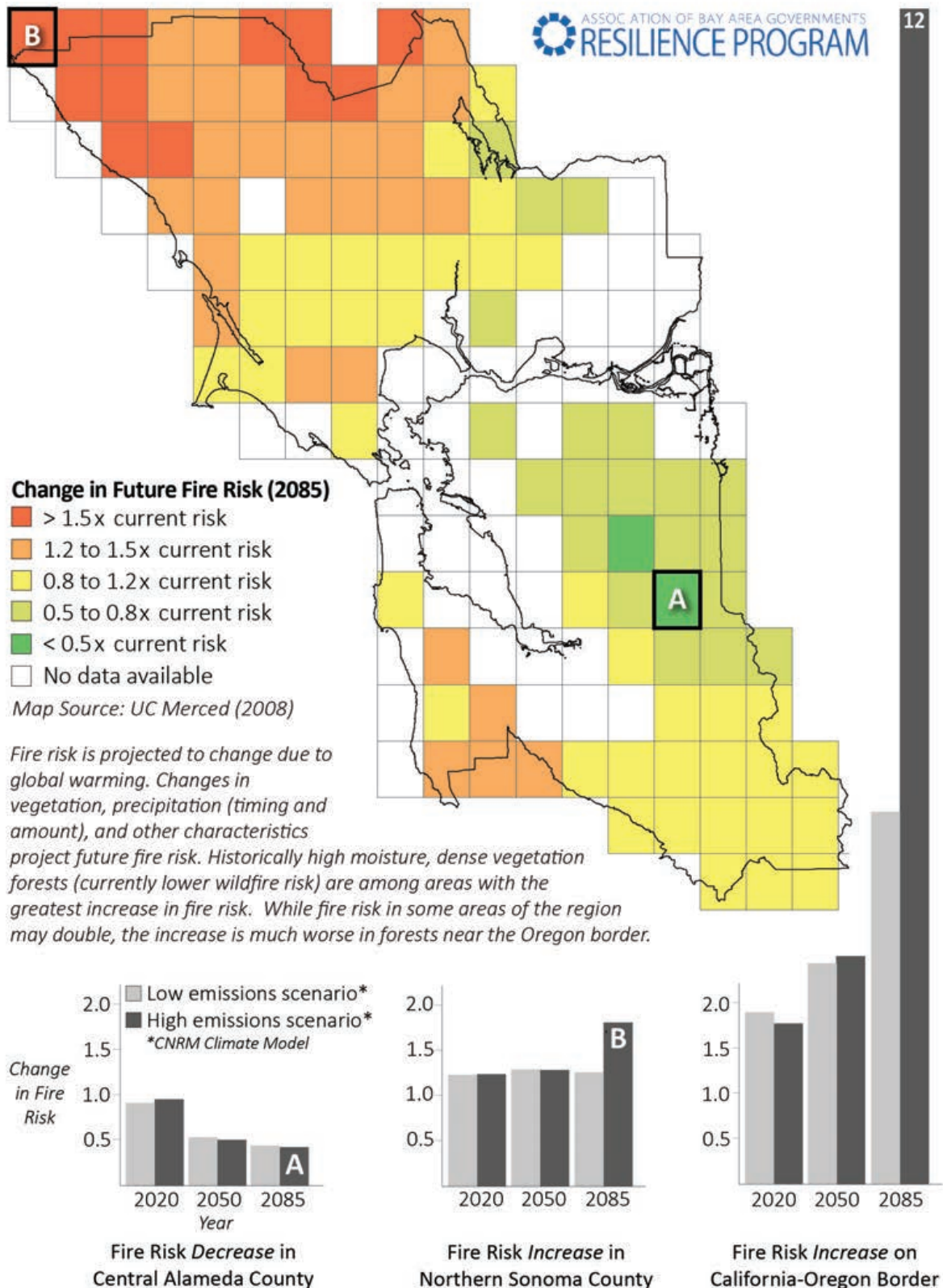


FIGURE 17 Climate Change Influence on Future Fire Risk



hazard severity takes into account the amount of vegetation, the topography, and weather (temperature, humidity, and wind), and represents the likelihood of an area burning over a 30-50 year time period. In Figure 18, shadowed portions of the map depict very high fire hazard severity in Local Responsibility Areas. Cal FIRE does not map other levels of fire hazard severity in local responsibility areas. Local Fire Departments and protection districts may have locally available hazard severity information for these areas.

CalFire also produced WUI maps that highlight areas with burnable vegetation and residential density greater than one unit per 20 acres. These zones represent areas of potential fire and high exposure of people and property. Figure 19 is a map of CalFire-designated WUI zones. Some local fire departments and districts have chosen to identify their own WUI zones based on their local knowledge of the landscape. Santa Rosa is one city example with a self-defined WUI Area.

### Burn Areas

The impacts of a fire are felt long after the fire is extinguished. In addition to the loss of property in fires, the loss in vegetation and changes in surface soils alters the environment. When all supporting vegetation is burned away, hillsides become destabilized and prone to erosion. The burnt surface soils are harder and absorb less water. When winter rains come, this leads to increased runoff, erosion, and landslides in hilly areas (see the landslide section on page XX for more information).

### Urban Conflagration

While the primary fire threat in the Bay Area is from wildfire, urban conflagration, or a large disastrous fire in an urban area is a major hazard that can occur due to many causes such as wildfires, earthquakes, gas leaks, chemical explosions, arson, or accidental ignitions. The urban fire conflagration that followed the 1906 San Francisco Earthquake did more damage than the earthquake itself. A source of danger to cities throughout human history, urban conflagration

has been reduced as a general source of risk to life and property through improvements in community design, construction materials, and fire protection systems.

Although the frequency of urban conflagration fires has been reduced, they remain a risk to human safety. A memorable example of urban conflagration linked to wildland is the 1991 Oakland Hills firestorm. The firestorm occurred within a larger high fire hazard zone that is part of an approximately 60 mile stretch of hills running from the Carquinez Strait to San Jose in the eastern San Francisco Bay Area. The fire happened in an economically well-off, largely built-out residential area that has a long standing fire history linked to hot, dry fall winds and the presence of dense, flammable vegetation.

## Drought

A drought is a gradual phenomenon that occurs over several dry years, depleting reservoirs and groundwater basins without the expected annual recharge from winter precipitation. While drought does not have any primary impacts in the Bay Area, prolonged periods of drought can cause secondary impacts that can affect the region, including:

- Reduced water supply for urban, agriculture, and environmental uses.
- Increased wildfire hazard, including more fire starts and more prolonged conflagrations fueled by excessively dry vegetation and reduced water supply for firefighting purposes
- Subsidence due to a lowering water table
- May be correlated with high heat conditions.

Drought is not localized, but occurs simultaneously across the region, and may extend statewide or across a larger expanse of western states. While drought may exist in every county, the impacts of the drought are locally unique, based on local water supply systems, soil conditions, and the typical climate and vegetation land covering. The effects of drought are managed in the Bay Area through the importation of water and the storage of water in reservoirs.

FIGURE 18 Fire Hazard Severity Zones

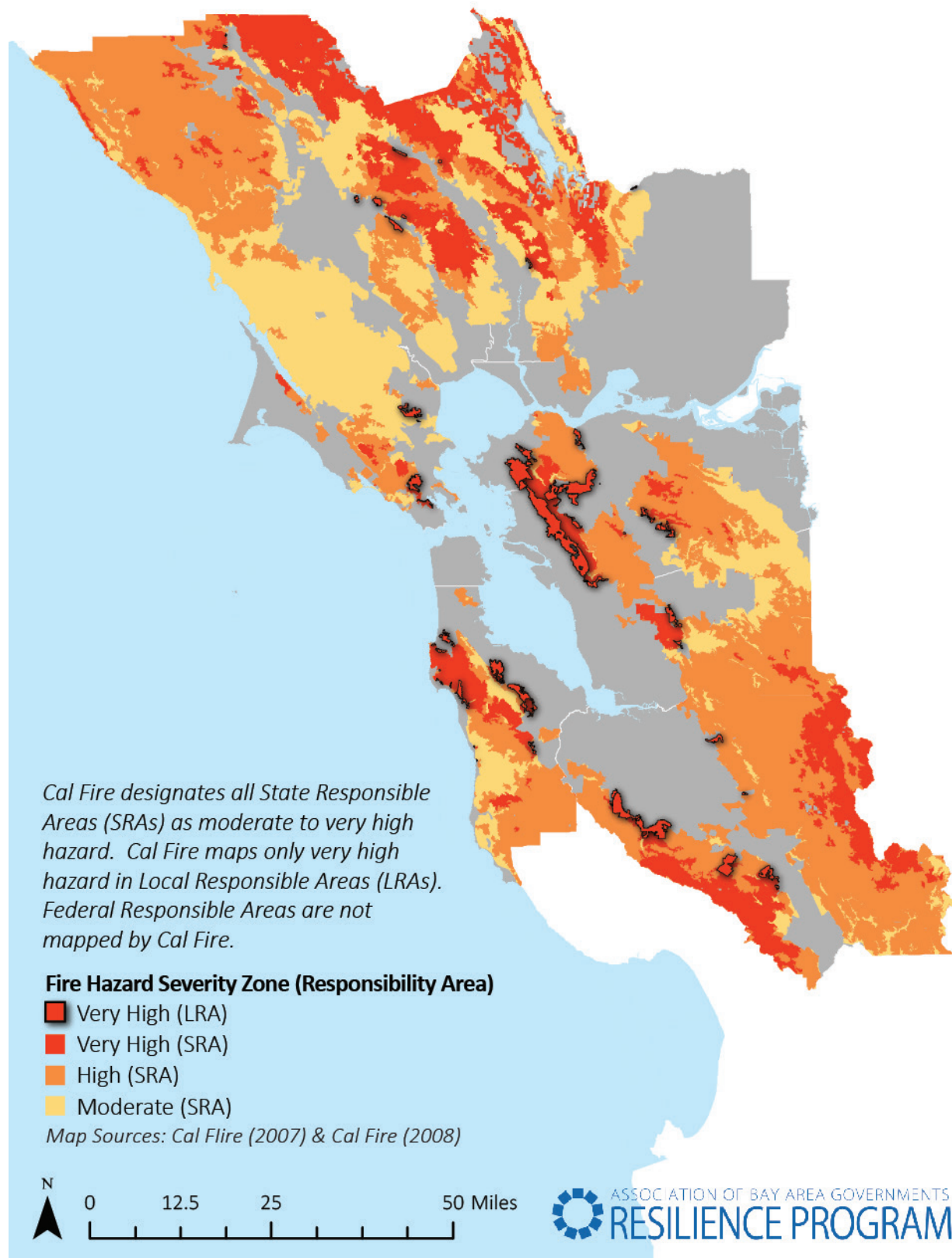
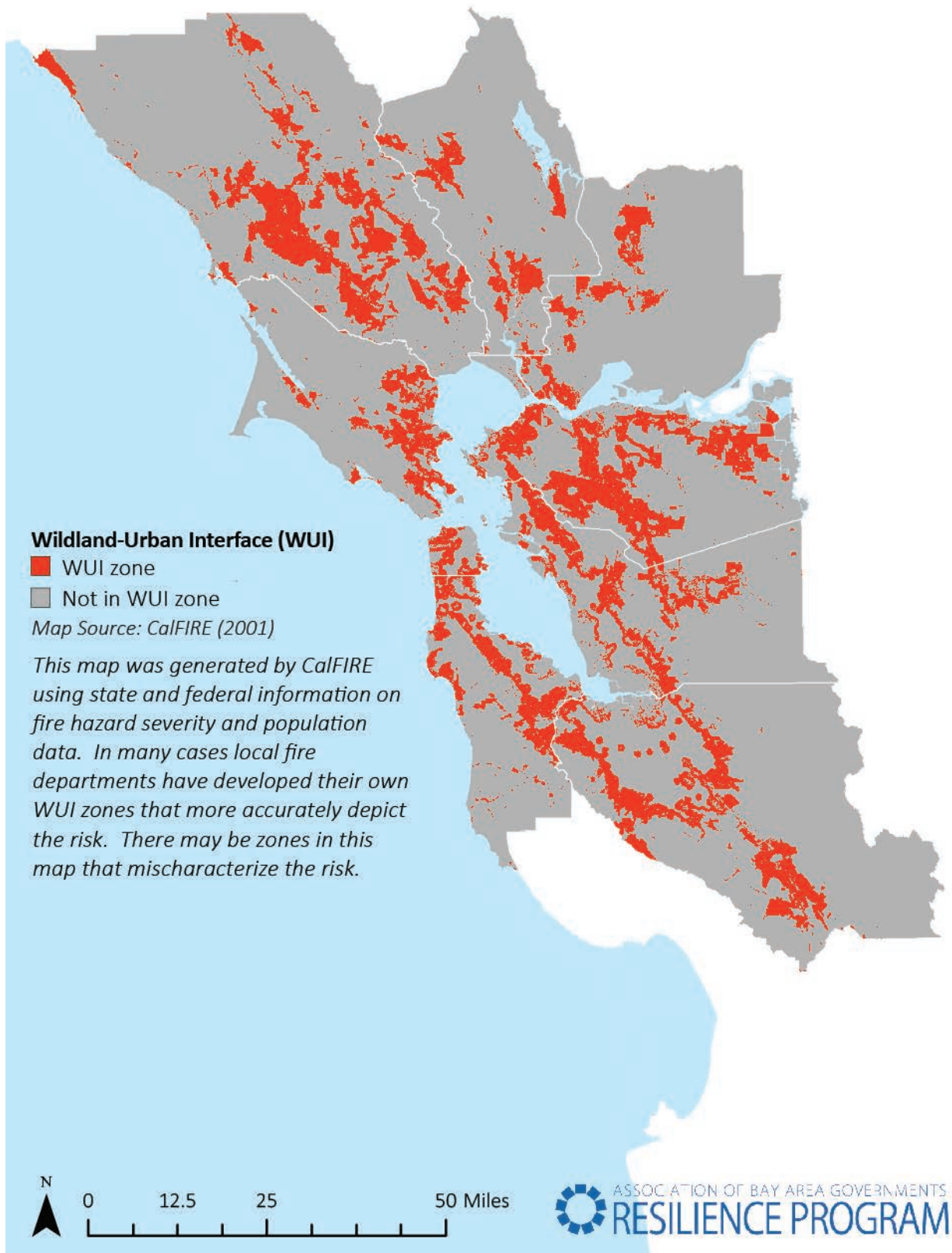


FIGURE 19 State Defined Wildland Urban Interface



The United States Drought Monitor is produced by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Department of Agriculture. The Monitor releases weekly maps of current drought conditions. NOAA also publishes one year outlook maps for temperature and precipitation. The maps project temperature and precipitation twelve months out – describing the conditions as likely below, above, or average.

## Historic Bay Area Drought Occurrences

Major droughts occurred in California that affected the Bay Area in 1973, 1976-77, 1987-1991, 2007-2009, and 2011-2016. Drought conditions in 1973 led to a state-declared disaster in Glenn, San Benito, and Santa Clara counties, resulting in \$8 million in agricultural loss. Between 1976 and 1977, California experienced one of its most severe droughts. 1977 was the state's driest year on record. In the Bay Area, Contra Costa, Napa, San Mateo, and Marin counties were four of the several counties where a state disaster was declared. Statewide, \$2.67 billion in damages occurred in the two-year period. Marin, Solano, and Sonoma counties were also affected in the 1987-1991 drought, which caused \$1.7 billion in crop losses nationwide. The 2007-2009 drought did not directly affect Bay Area counties, but caused \$300 million in crop loss statewide.

In January 2014, the Governor declared a State of Emergency in California in response to current drought conditions, which began in 2011. The most recent drought was characterized as the driest five-years on record for the state.

## Probability of Future Drought – Climate Influenced

Climate change is likely to increase the number and severity of future droughts. The cumulative impact of climate change impacts will result in drier conditions, and alter the timing and efficiency of the Bay Area water supply. An increase in temperature and a reduction in snow pack are the two most direct effects of climate change that will result in a drier state with fewer natural water resources than historically have been available.

In the Bay Area temperatures are projected to increase between 3 degrees (low emission scenario) and 6 degrees Fahrenheit (high emission scenario). In the eastern regions of the state the increase is 4 to 9 degrees.

The reduction in snowpack does not have direct impacts in the Bay Area as the region does not accumulate meaningful levels of snow. The Bay Area is adversely impacted by the severe reduction in snow pack in the Sierras, the source of two-thirds of the region's water. By the end of the century the spring snow pack in the Sierra could be reduced by as much as 70 to 90 percent the historic average.

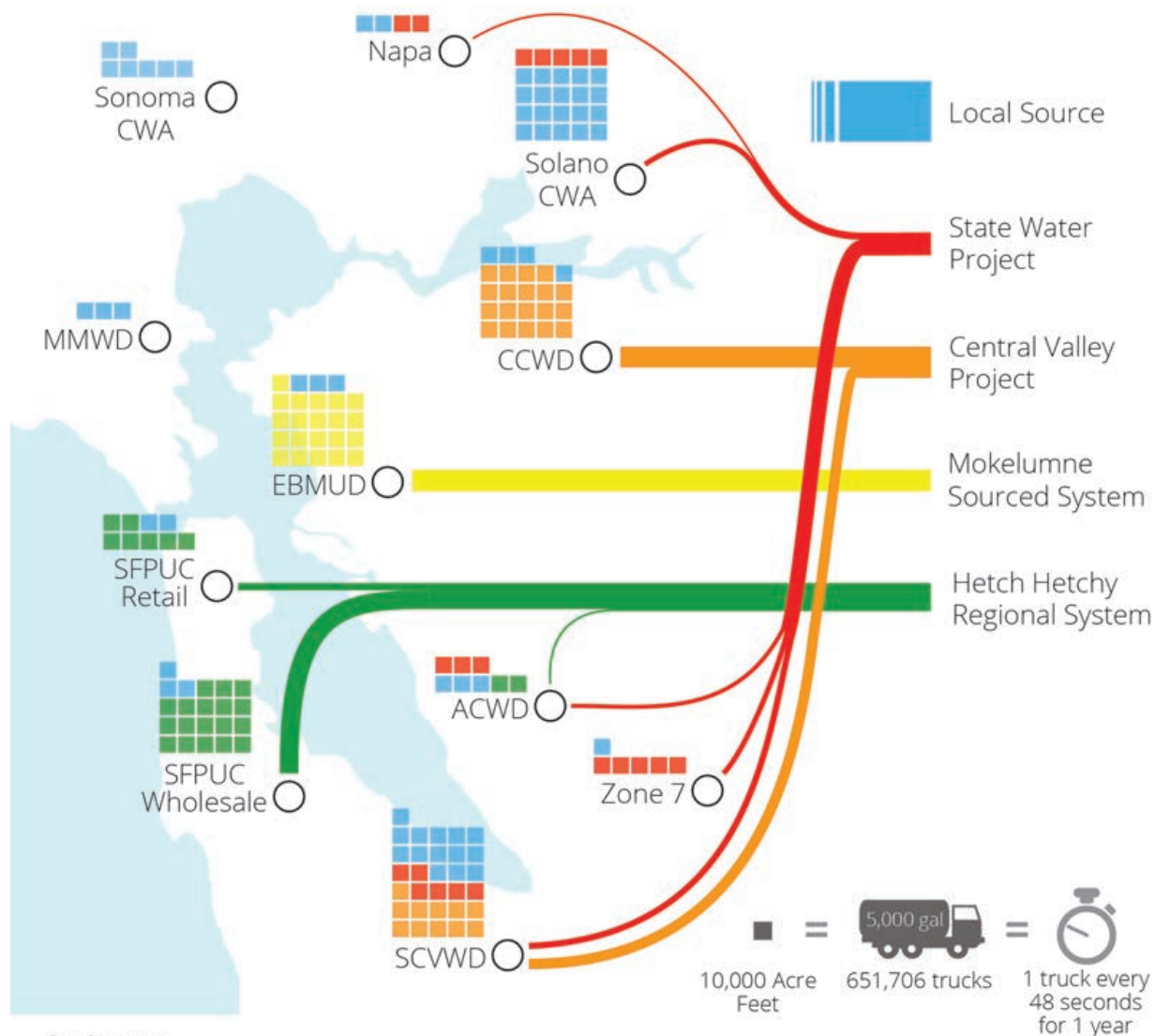
## Drought Hazard in the Bay Area

### Water Supply

Drought can impact the entire Bay Area, not just one particular county or a few cities. In addition, shortages in precipitation in the Sierra Nevada can have a more pronounced impact on water supply in the region than a drought in the Bay Area itself because of the reliance of the region on water from the Tuolumne, Mokelumne, Sacramento, and San Joaquin watersheds. Thus, drought is not a hazard that can be depicted by a Bay Area map; rather a map of Northern California is necessary to understand the impact of drought on Bay Area water supply.

Figure 20 illustrates where the largest water districts in the region collect water. Only a third of the water used in the Bay Area is from local rainfall collection and groundwater pumping; the remainder comes from runoff in the Sierra Nevada Mountains. Figure 21 highlights the severity of the current drought in watersheds Bay Area districts are dependent on for their water. In 2015, portions of the Bay Area were downgraded slightly because of average rainfall in micro climates of the region. Other portions of the Bay Area, and most of the area the region relies on for its imported water, remain in exceptional drought, the highest drought designation.

**FIGURE 20** Water Source Portfolio and Annual Normal Supply



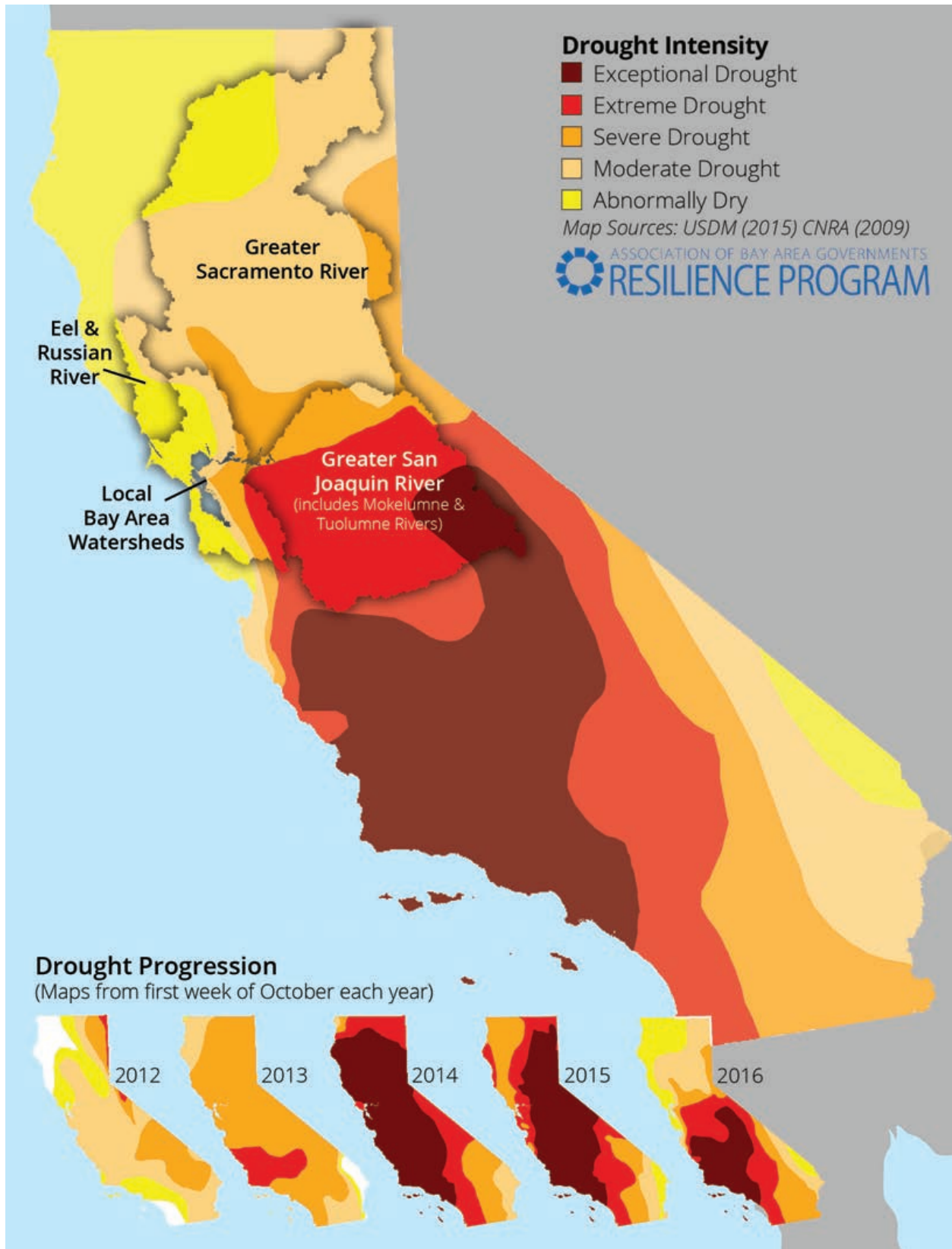
*Graphic Notes:*

1. SFPUC Wholesale, is a category that includes 25 of the 26 BAWSCA agencies, excluding ACWD which was operated because of their size as well as their connection to the State Water Project.
2. The lines are not representative of pipeline locations.

Data Source: 2010 Urban Water Management Plans

ASSOCIATION OF BAY AREA GOVERNMENTS  
**RESILIENCE PROGRAM**

**FIGURE 21** California Drought in Watersheds the Bay Area Relies On



## Increased Fire Hazard

Fire hazard increases where drought conditions are high. There are multiple drought related factors that contribute to increased fire hazard: longer fire season, drier vegetation, and hot days. Additionally, drought reduces the water supplies available to fight wildfires, leading to larger and more extended fires. When in a drought, the fire risk is greater, and the impacts remain the same, as those described in the fire section on page XX.

## Subsidence

The most commonly measured impact of land subsidence is vertical land displacement. Subsidence can lower the ground surface, making low-lying areas more vulnerable to flooding and inundation. Subsidence can also change the elevation and slope of waterways such as streams and canals; cause damage to infrastructure such as bridges, roads, railroads, sanitary sewers, and levees; and, damage buildings. Subsidence becomes an especially challenging problem in areas along the coastline or bay shoreline as it will increase the risk of flooding.

Some Bay Area jurisdictions rely on ground water resources for their typical year water supply (see Figure 20). Subsidence can occur when more groundwater is removed than is naturally replenished. Subsidence can cause damage to building foundations and can impact infrastructure, and can cause land to become more vulnerable to flooding. When there are average rain events and average water usage, the region for the most part has become responsible in how it pumps groundwater, averting subsidence. This was not always the case – for the majority of the 20th century, the Santa Clara Valley relied on a large aquifer for its water needs, causing the entire valley to subside as much as eight feet between 1934 and 1967. Since then, regulation requiring a switch to imported water has greatly reduced the rate of subsidence. Water management plans have done well to prevent subsidence in average rainfall times. When droughts occur, however, many jurisdictions change their water source profile, often drawing greater amounts of water from the ground. This

can result in subsidence which occurs when discharge outpaces recharge. During the current drought jurisdictions across the state have drawn water out of the ground at unsustainable rates, in some places dropping the water table 15 to 20 feet just between 2011 and 2014.

Subsidence can cause changes to an aquifer. Land subsidence does not impact the useable aquifer storage space; however, it does impact the ease and rate at which groundwater can be drawn from the ground. To obtain the same amount of water from the aquifer where the land has subsided requires either more time or greater pumping force.

## High heat conditions – Location & Severity

High heat conditions, which can occur in greater frequency during drought are discussed in greater detail in the next section on extreme heat.

## Extreme Heat

The Bay Area, especially away from the coast and bay, can experience extreme heat days, where the Heat Index, a function of heat and relative humidity, is high. Extreme heat days pose a public health threat, causing symptoms such as exhaustion, heat cramps, and sunstroke if the Heat Index is over 90°F. The National Weather Service has developed a Heat Index Program Alert which gets triggered when high temperatures are expected to exceed 105° to 110° for at least two consecutive days. Heat emergencies occur when residents are subject to heat exhaustion and heatstroke, and are more likely to occur in areas not adapted to heat and without air conditioning, cooling centers, or vegetation to mediate heat impacts in exposed areas. Certain populations are typically the most at risk during extreme heat emergencies, including people with disabilities, chronic diseases, the elderly, and children.

Extreme heat emergencies typically build over time with cumulative effects. Because of this, and the fact that they do not cause substantial physical damage to the built environment, they do not elicit the same immediate response that

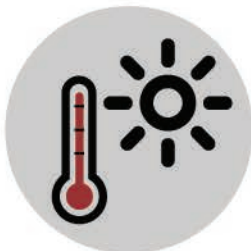
**FIGURE 22** Extreme Heat Impacts Modeled with Cal-Adapt and Extreme Heat Effects



Extreme heat impacts can be viewed at the city scale using Cal-Adapt, a resource that synthesizes existing climate impact research. Cal-Adapt's extreme heat tool has six chart features: (1) number of extreme heat days, (2) number of warm nights, (3) number of heat waves, (4) maximum duration of heat waves, (5) timing of extreme heat days, and (6) daily high temperatures, each by year (1950-2099). Below are two example outputs for the Suisun Bay Quadrant.

### Extreme Heat Effects<sup>2</sup>

<sup>2</sup>Preparing California for Extreme Heat (CalEPA, 2013)



#### Heat Related Illnesses

Individual hot days as well as heat waves and consistently warm nights have significant health impacts. In a 2006 California heatwave studies estimated 655 deaths were associated.

**Air Quality**  
Higher temperatures favor the formation of ground-level ozone and other secondary air pollutants created from chemical reactions with pollutants.

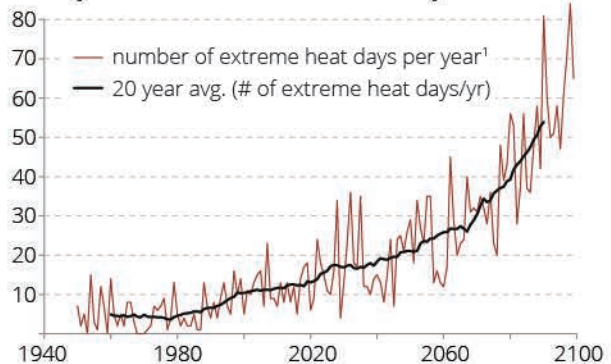


#### Increased Energy Demand

High temperatures result in peak energy demands to power air conditioning systems. In some cases, excessive energy demand may result in rolling blackouts.

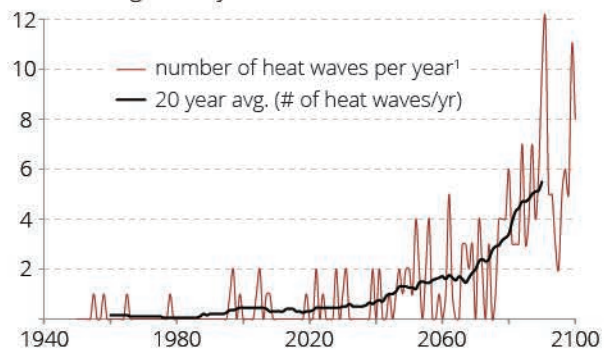


An **extreme heat day** means different things for different locations. It is calculated by taking the 98th percentile of historic maximum temperature. In San Francisco County an extreme heat day is defined as a day above 78°, while for inland portions of Solano County extreme heat is defined as a day above 100°.



<sup>1</sup>From CalAdapt's Extreme Heat Tool using the GFDL scientific model for the quadrant which includes Martinez, CA and Suisun Bay.

Extreme heat is made worse when it is experienced over a longer stretch of time. The number of **heat waves** (five or more consecutive days of extreme heat) will increase as will the length of heat waves. By the end of the century most of the region will average six heat waves a year, with the average longest heat wave lasting ten days.



<sup>1</sup>From CalAdapt's Extreme Heat Tool using the GFDL scientific model for the quadrant which includes Martinez, CA and Suisun Bay.

other hazards do. However, they claim many lives in comparison to other disasters. The California Climate Adaptation Strategy, citing a California Energy Commission Study, states that heat waves have claimed more lives in California than all other disaster events combined.

## Historic Extreme Heat

No heat emergencies in California have been declared a disaster at the state or federal level between 1960 and 2008. The Spatial Hazard Events and Loss Data for the United States estimates approximately 47 heat events in California during this time. In 2006 a notable heat wave spread throughout most of the United States and Canada, causing 140 fatalities in California.

## Probability of Future Extreme Heat

Climate change is expected to generate an increase in ambient average air temperature, particularly in the summer. The outer Bay Area will likely experience greater temperature increases than coastal or bayside jurisdictions, though likely not as great as in the eastern-most inland counties of California. The frequency, intensity, and duration of extreme heat events and heat waves are also expected as regional climate impacts.

According to California Climate Change Center, by mid-century, extreme heat in urban centers could cause two to three times more heat-related deaths than occur today.

## Extreme Heat Hazard in the Bay Area

The Bay Area has historically experienced 4 extreme heat days a year. Depending on low and high greenhouse gas emission scenarios, and the location within the region, in the future a city may experience an average of anywhere from 20 to 80 extreme heat days in a year. The different greenhouse gas emission scenarios model future temperatures based on either reduced global CO<sub>2</sub> emissions or the continuance of existing emissions.

Cal-Adapt, California's database of climate information and visualization tools provides five different ways to define the extreme heat hazard:

1. Number of extreme heat days by year
2. Number of warm nights by year
3. Number of heat waves by year (heat wave is defined as 5 consecutive extreme heat days)
4. Timing of extreme heat days by year (i.e. which months do extreme heat hazards occur)
5. The maximum duration of heat wave by year.

These metrics are projecting both the intensity and the temporal nature of extreme heat.

## Intensity

The intensity of extreme heat is defined differently for each location in the region. In San Francisco County an extreme heat day is defined as a day above 78°, while for inland portions of Solano County extreme heat is defined as a day above 100°. The threshold is the 98th percentile historic maximum temperature. The threshold is set locally to recognize services and buildings in cooler climates may not be designed to handle moderate heat, while those areas where high heat has historically occurred, already have measures to address their historic temperatures.

In addition to the number of extreme heat days expected to rise in the Bay Area, the temperature is expected to increase well above thresholds over the next century. In San Francisco County by the end of the century there could be multiple days a year where temperatures reach 95°, while in Solano County there may be multiple days above 115° each year.

## Temporal

Extreme heat is made worse when it is experienced over a longer stretch of time. The number of heat waves (five or more consecutive days of extreme heat) will increase as will the length of heat waves. By the end of the century

most of the region will average six heat waves a year, with the average longest heat wave lasting ten days. In addition to the more frequent occurrence and duration of heat waves, they are expected to occur in months the region historically hasn't experienced extreme heat. Historically, extreme heat occurs between July and August, but in the future extreme heat will be an issue the region faces in both the Spring and Fall.

## Additional Hazards

The hazards outlined in this chapter represent those that pose the greatest impacts to the Bay Area region as a whole. However, there are other hazards that may cause localized impacts or may pose less of a threat to the region. They may be discussed in more detail in Local Hazard Mitigation Plans, as appropriate. These are discussed briefly below. These hazards, and many more, are characterized in the 2013 California State Hazard Mitigation Plan.

### 3.7.1 Dam Failure

Many of the dams built in the Bay Area over the last 150 years were built before there were sophisticated seismic engineering standards and applicable government regulation. Dams can be damaged by large storms and the associated runoff, an earthquake, slope failures, or a terrorism event. While dam failure is rare, their failure can be catastrophic, destroying downstream structures and killing people, while reducing water supply to the Bay Area until the dam is rebuilt.

In the 1970s, the state mandated the development of maps showing potential inundation areas due to dam failure. However, the methodology of these maps was limited and they have not been updated since, so they are generally no longer used. Additionally, when a dam is known to have a failure potential, the water level is reduced to allow for partial collapse without loss of water, as required by the State Division of Safety of Dams. Dam owners are required to routinely inspect their facilities and reevaluate their safety in light

of current engineering and seismology, and many Bay Area dams have been retrofitted because of this.

There has never been a large dam failure in the Bay Area. However, the potential property losses from catastrophic failure are enormous, considering the amount of development within potential inundation zones. Additionally, a dam is most likely to fail as a result of an earthquake, which would lead to its own catastrophic property damage.

### 3.7.2 Levee Failure

The Sacramento-San Joaquin River Delta and Suisun Marsh are vitally important to the Bay Area economy and environment and contain many levees. The region contains highly fertile agricultural land and provides a unique habitat to many estuarine animals. The Delta region contains critical infrastructure including pipelines, highways, and power and communication lines. The Delta is the hub of the California water system, providing water to 25 million people in the State and 3 million acres of farmland. The probability of levee failure is increasing over time due to sea level rise, increased flooding potential due to early winter snow melts, and the likelihood of an earthquake.

An earthquake is the single biggest risk the Delta Region faces. If an earthquake occurs, levees may fail and as many as 20 or more islands could be flooded instantaneously. This would result in an economic impact of \$15 billion or more. Some researchers have estimated the likelihood of a multiple levee failure disaster at about two percent per year. Little is known about the local faults in the Delta. These have only exhibited a low-level pattern of scattered small earthquakes since 1966, but are still believed to be capable of moderate to strong earthquakes ( $M > 6.0$ ). While local Delta faults contribute most significantly to the hazard at longer return periods, and will produce stronger shaking due to their proximity to the levees, the major Bay Area faults pose a greater risk to the Delta levees. While they are farther away and will produce smaller ground motions at Delta sites, earthquakes occur much more frequently on these faults. The Hayward fault, in particular, is the

greatest concern for the Bay Area. It is capable of producing large earthquakes that will be devastating to the Bay Area and is close enough to the Delta to damage levees. Other Bay Area faults, such as the Concord and Green Valley, are also likely to produce earthquakes that will damage Delta levees. Additionally, the soils in the western delta are extremely weak and liquefaction will trigger at even low levels of shaking.

Much of the land in the Delta Region is below sea level and is protected by approximately 1,115 miles of levees in the Delta and 230 miles of levees in the Suisun Marsh. The majority of these levees were constructed at heights of three to five feet high and were maintained by local

landowners in the last 130 years to protect farm land from flooding inundation. As a result of land subsidence, sea level rise and increased demand for land in the delta, these levees have been raised and increased in length over the years. Today, most of these levees retain water 365 days a year, and carry additional loads during flood events.

While levees of Delta islands fail occasionally, these occurrences typically are not within the nine-county San Francisco Bay Area. Delta levee failures outside the nine county Bay Area threaten critical infrastructure in the Delta and a portion of the Bay Area and Southern California water supply. Levees are extremely slow to be repaired and economic and social consequences would be protracted.



# BAY AREA ASSETS AT RISK







# Bay Area Assets at Risk

Understanding the impacts of hazards on people, buildings, infrastructure, and natural resources can give your community an understanding of your overall vulnerabilities, why hazards matter in your community, and can help guide more appropriate and responsive mitigation strategies. Each asset class is examined from the perspective of being able to withstand the disaster as well as how it will impact a community's recovery from a disaster.

The chapter has four sections: people, buildings, infrastructure, and natural resources. Each section characterizes the importance of each asset class, with an emphasis on its function, and then outlines the most common physical and functional vulnerabilities for that asset class. Physical vulnerabilities include how the asset can be physically damaged by a disaster, and functional vulnerabilities include ways in which hazards can impact the ability of the asset to function as needed.

## Bay Area Assets

After a disaster, community vitality is dependent upon people, buildings, utility and transportation infrastructure, and natural resources. Each of these assets contributes unique benefits to the community, and each has specific vulnerabilities to disasters. This chapter describes the role of these assets and how they are each uniquely vulnerable. Without an understanding of the asset's role, there is no basis to understand what damage means for the community.

**People** experience hazards through damage to buildings and interruption of infrastructure services. Some people may be directly injured or killed by hazards, but this is only a portion of the impacts on people. The vast majority of impacts will be felt through a person's ability to manage the secondary impacts from the hazard.

*Social vulnerability* describes characteristics that make people less able to adequately withstand and adapt to a hazard, such as limited mobility, income, and educational attainment. Social vulnerabilities are largely independent of the hazard type and can be applied similarly to any type of disaster.

**Buildings, Utility and Transportation Infrastructure & Natural Resources** support community vitality. Impacts to the built and natural environment can have significant consequences to the people who live and work in the buildings and depend on the functions infrastructure and natural resources provide. The built and natural environments are impacted by disasters primarily in two ways:

*Physical vulnerability* describes how an asset can be physically damaged by a disaster. Because buildings, infrastructure, and natural resources are uniquely vulnerable to different hazards, they are described hazard by hazard.

*Functional vulnerability* describes ways in which hazards can impact the ability of the asset to function as needed, either directly or indirectly, such as by limiting a sewer treatment plant's ability to operate if power is unavailable.

## People

The character of Bay Area residents is responsible for the region's strong community vitality, distinctive culture, and unique economy. The Bay Area is especially diverse, showcasing many different lifestyles, cultures, and languages that provide a wide variety of cultural experiences. Longtime residents of the region have special knowledge, social networks, and cultural memories that make them strong stewards for neighborhoods, parks, and trails. If a disaster forces Bay Area residents from their homes, social networks will be broken, and the diverse culture of the region will change.

The Bay Area's economy relies on service, labor, creative, and professional workers. The Bay Area economy is unique in that it is home to one of the fastest growing and most innovative economic sectors in the world. If a disaster impedes the ability of employees of any sector to stay in the region or get to work, the impact will cascade beyond individual businesses and be felt not just across the region, but nationally or even globally. Employees from all sectors are needed to support one of the strongest and most specialized economies in the world.

People are a critical asset for the functioning of a community and the economy; without residents a jurisdiction loses its tax base and employers lose employees and customers. More importantly, jurisdictions lose the culture, vibrancy, and sense of cohesiveness that make it unique. Jurisdictions in the Bay Area should understand that people are the nexus of a resilient community, and many other assets are designed to serve and support people.

### Social Vulnerability

Unlike other asset classes such as buildings and infrastructure, the vulnerability of people is not just due to physical characteristics but rather social characteristics that make them less able to adequately withstand and adapt to a hazard. People are also highly dependent upon the physical environment that they are surrounded by;

community members are much more vulnerable if the buildings and infrastructure that they live in, work in, and rely upon fail.

In 2015, ABAG and BCDC published *Stronger Housing, Safer Communities*, a report that identified ten primary indicators that represent characteristics of individuals and households that affect their ability to prepare for, respond to, and recover from a disaster. These indicators collectively present a picture of a community's vulnerability to stressors. Concentration of these indicators, or areas with multiple indicators, can inhibit the recovery of a community. Using Census data, ABAG and BCDC mapped community vulnerability in the region (see Figure 22). The data used to create this map is available on the ABAG Resilience Program's Open Data website. Key themes that emerged included age-related vulnerabilities, language and ethnicity vulnerabilities, cost-burdened residents, housing tenure issues, and access to resources. Indicators were measured and scored using the method developed by the Metropolitan Transportation Commission (MTC) to identify Communities of Concern (CoC). This is meant to identify block groups with higher than average concentrations of the particular indicator and therefore may have higher concentrations of vulnerability. The

### STRONGER HOUSING SAFER COMMUNITIES: STRATEGIES FOR SEISMIC AND FLOOD RISKS

ABAG & BCDC published *Stronger Housing, Safer Communities* in 2015, which studied the vulnerability of Bay Area housing and its residents to natural disasters. The report identified and mapped the housing types in the Bay Area most likely to be damaged by earthquake ground shaking or liquefaction and flooding as well as ten indicators of social vulnerability, including income, race, and education levels. Forty strategies for state, regional, and local governments were developed to address these specific vulnerability types and are available in the report

and in an online database. For more information visit: [resilience.abag.ca.gov/projects/stronger\\_housing\\_safer\\_communities\\_2015/](https://resilience.abag.ca.gov/projects/stronger_housing_safer_communities_2015/)

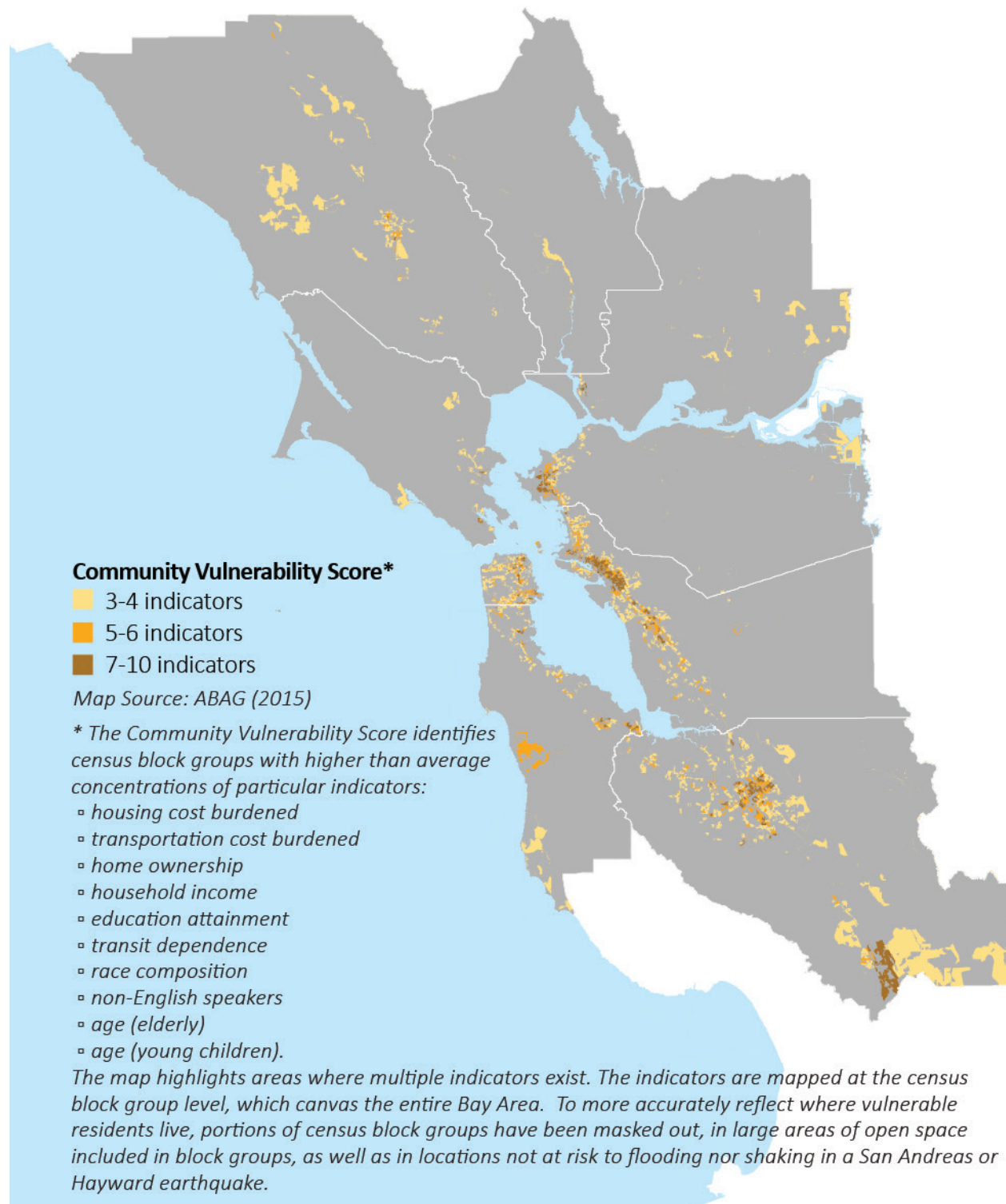


**TABLE 6** Community Vulnerability Characteristics

Indicator	Measure
Housing cost burden	% household monthly housing >50% of gross monthly income
Transportation cost burden	% household monthly transportation costs >5% of gross monthly income
Home ownership	% not owner occupied housing
Household income	% households with income less than 50% AMI
Education	% persons without a high school diploma >18 years
Racial/Cultural Composition	% non-white
Transit dependence	% households without a vehicle
Non-English speakers	% households where no one ≥ 15 speaks English well
Age – Young children	% young children under 5 years
Age – Elderly	% elderly, over 75 years

ABAG & BCDC (2015) *Stronger Housing & Safer Communities Report*

**FIGURE 22** Community Vulnerability in High Hazard (Flooding & Earthquake) Areas



following table includes the ten indicators that contribute to the vulnerability of people and households.

The following sections describe the most common characteristics that make people more vulnerable to the consequences of a major disaster.

### **Income**

Residents who are resource constrained are more vulnerable to the impacts of a disaster. Resource-constrained residents include households that are low- and very low-income, households of all income levels that spend large percentages of their income on housing and transportation, and transit-dependent households that do not own a car. Resource-limited households are less able to prepare for natural disasters, and if displaced from damaged homes, will likely struggle to find housing that is affordable and near to the jobs, schools, medical facilities, and other services on which they rely.

### **Access to Housing**

Unaffordable housing also contributes to the vulnerability of residents and will become significantly exacerbated after a disaster. Much of the region is cost-burdened with regard to housing already, spending 30 percent or more of their income on housing. After a disaster, if many housing units are lost, a constrained market may drive up the cost of housing even further. Loss or damage of housing that results in increased costs to either renters or home-owners will likely increase the number of permanently displaced Bay Area residents as finding housing that is affordable and near jobs, schools, medical facilities, and other services on which they rely will be challenging.

Many Bay Area residents that live in areas at risk from natural disasters are low-income renters or those who live in multi-family housing. It is generally more difficult for residents in multi-family housing (either renters or owners) to retrofit their housing and many do not have insurance to protect themselves and their belongings in case of a disaster. In many communities, renters

are also more likely to be resource-limited (low income, cost burdened, or lacking savings) and will need assistance both during a disaster (e.g., with shelter-in-place facilities), as well as post-disaster with finding interim, affordable housing to avoid the permanent displacement of low income or cost-burdened renters from communities due to damaged housing.

### **Access to Information**

Access to timely, correct, and meaningful information about hazard risks and how to access resources, both before and after a natural disaster, can be challenging in all communities and can be a particular challenge in communities that are ethnically and culturally diverse, and where there is a large number of households in which English is not the primary language spoken. Additionally, in the Bay Area many of these same community members are resource-constrained renters who are often living in overcrowded housing.

Up-to-date and easily accessible information about the number of elderly, very young, and mobility challenged living in a community can be challenging to find, particularly during a disaster when it is most needed. It can be difficult to evacuate these community members, especially if they need specialized equipment or supervision, and shelter-in-place facilities need to be prepared to house them safely and maintain communication with concerned family members.

### **Access to Social Networks**

Additionally, residents who do not have a strong community network are more likely to leave the area after a disaster or struggle to recover. After Hurricane Katrina and many other past disasters, community cohesion was critical to disaster recovery. It allows residents to meet their needs through their community rather than solely relying on themselves or government assistance. Communities are more likely to be able to advocate for themselves and spread knowledge about mitigation, preparedness, and recovery actions than individuals. Therefore, neighborhoods

with a strong sense of community, with active churches, social groups, or long-term residents, may be less vulnerable to disasters despite exhibiting some or many of the indicators above, while young, more transient residents may in fact be more vulnerable despite higher education and income levels.

## Buildings

One of the most commonly reported disaster metrics is the number of damaged and destroyed buildings. The overall extent of damage is telling, but not every damaged building will have an equal impact on a community. Certain building uses, and the extent of damage to individual buildings, can have a great influence on the ability of a community to recover from a disaster. Understanding the function of the building stock and the potential for damage is central to understanding the impact that disasters have on people's lives and on the ability to recover.

Housing, employment centers, and critical facilities are featured because of their important role in the fabric of a community and because they can significantly affect recovery. Each building use has unique functional vulnerabilities as the community relies on each building sector for different critical needs. However, the physical vulnerabilities of the buildings are not the same across different building uses and instead vary by building construction type and by hazard. Different construction types may respond differently to a disaster, and buildings may also respond differently to different disasters. When assessing potential disaster impacts it is important to consider both the physical vulnerability of the building that could lead to damage in a hazard event, and the functional vulnerability of the building, including what services it provides and who it serves, that would be interrupted or displaced.

Beyond essential services, many communities' buildings also contribute greatly to the character and history of the community. Historic buildings contribute to a sense of community and may also contribute to the local economy. Historic buildings

are typically more vulnerable to disasters because they were built to previous building codes (or no building codes at all), but their importance in a community can be great. If these buildings are lost, the entire character of a community can change. Therefore historic buildings should be given extra consideration, particularly if a community's goals include the preservation of local and historic character.

## Building Function Types

### Housing

Retaining housing is crucial to expediting and ensuring an effective disaster recovery. Limiting catastrophic housing damage and keeping residents in their homes not only helps people who may lack the resources to effectively recover from a disaster, but also keeps communities intact. If residents are able to stay in their community, they can continue to assist recovery and rebuilding efforts, and support local businesses. Many community members, especially those who exhibit vulnerability characteristics described in the people section on page XX, are highly dependent upon the housing they live in as a critical factor in their resilience to a major disaster.

Multiple studies have shown that population loss after a disaster significantly slows recovery time. In the Bay Area, much of the older, more affordable housing stock is at risk to damage in a disaster. Many homeowners may not have the resources to stay and rebuild if their homes are significantly damaged, and renters displaced by damaged housing will be forced to find other rental housing. Past disasters have demonstrated that low-income or rental housing often gets demolished and rebuilt as market rate housing, permanently changing community and regional demographics. Thus, keeping housing intact is fundamental to community stability. In the aftermath of natural disasters, the recovery of the region's economy is interdependent with the recovery of the region's housing. If residents can stay in their homes, they will be better able to participate in the rebuilding of their neighborhoods and cities, go to work and support local business, and improve the recovery trajectory of the entire region.

Beyond providing shelter, homes are also a financial asset for homeowners. For most owners, their home is their largest financial asset, and is something they leverage to finance other spending (cars, tuition, etc.). For many, especially in the Bay Area housing market, a home represents the single largest investment an owner will ever make. The damage or loss of housing is a real threat to the investment that many homeowners have made, and many homeowners choose not to purchase earthquake insurance, since it tends to have high premiums and deductibles. Even those with insurance may not have adequate financial coverage. However, even if a home is demolished, the homeowner is responsible for the remainder of the home loan. Following a major disaster, owners with severely damaged or destroyed homes may have to default on their loan and walk away from their property at a significant loss if they're unable to accumulate enough financial support to repair or rebuild.

While it is widely assumed that new housing is built to a standard that provides adequate protection for residents, current code is designed to protect from loss of life, not necessarily reducing damage to the building. Newly constructed homes may still experience significant damage, displacing and creating financial hardship for residents. This is especially true for homes in liquefaction and flooding areas. New housing and future growth should be given sufficient consideration for both current and future hazards.

### Employment centers

In a major natural disaster in the Bay Area, many businesses will close due to building damage, inventory loss, utility outages, supply chain disruptions, inability of employees get to work, or a loss of customer base. For businesses further removed from the hardest hit areas, disruption may last only a few days or weeks. For harder hit businesses, disruptions could be much longer, forcing them to close permanently or move elsewhere, either nearby or in an entirely different region.

Other factors likely to impact economic recovery include the dependency of businesses on

our regional infrastructure systems—water, sewer, power, and access to broadband and communication—which are key to business operation and continuity. Ongoing infrastructure disruptions or unreliability will challenge businesses. Public transit, roads and highways are essential for the workforce to travel to work, particularly when more than half of Bay Area residents reside in a different county than where they work. The recovery of the education sector is also key— K-12 schools not only provide education to children, but provide the daycare that allows parents to return to work. Long school closures due to structural damage or prolonged shelter use will delay return of employees to work.

The Bay Area functions as an integrated economic unit, meaning that among the counties in the region there is a high degree of interconnectedness between where people work and live. All of the counties and sub-regions are highly dependent on one another for their economic functioning and on the region's transportation network. In addition, the Bay Area contains clusters of highly specialized and interdependent businesses, such as the tech sector in Silicon Valley. As these businesses are closely located, a disaster could have significant impact on an entire sector, affecting not just the Bay Area but state, national, and global economies.

The impact of natural disasters is disproportionately felt by different business sectors and by different business sizes. The construction sector often experiences a boost in activity to repair and replace damaged buildings and infrastructure, while most other sectors experience significant downturns. For example, the Port of Kobe, Japan ranked sixth in port traffic globally prior to a major earthquake in 1995. The port dropped to 24th during recovery, and even after repairs were finished, never surpassed 17th.

Other potential barriers to economic recovery include the disruption of vendors and supply chains to and from the region and the repercussions for national and international markets. Business disruption has upstream and downstream impacts on supply chains that can exacerbate impacts on the economy. For example,

disruption of a manufacturing business may limit global supply of a particular product, impacting the economy far beyond the original area. While the Bay Area's share of the manufacturing industry is not particularly concentrated, what is manufactured here is highly specialized and focused on sophisticated equipment design and development. Disruption of this specialized design and manufacturing could have global economic impacts or affect long-term growth in the region.

On the other side of the supply chain, inability to get goods into the damaged area can cause a shortage of goods for daily needs as well as materials and labor for rebuilding. Many businesses today operate with a "just-in-time" model for goods deliveries, stocking only enough to last until the next delivery. The transportation and shipping industries are critical in a "just-in-time" era – businesses need fast availability of goods in constrained environments. After a disaster, small or no stockpiles coupled with an inability to deliver new goods can have major implications on response and recovery. For example, many hospitals store limited quantities of medical supplies and rely on frequent regular deliveries of supplies.

Just as different sectors are impacted differently, businesses of varying sizes can recover very differently. A large portion of the Bay Area's economic activity is based on small businesses. Small businesses are valuable contributors to the economic and cultural vitality of the region, but an estimated 25 percent of small businesses do not re-open following severe disruptions from a major disaster. Many of these businesses provide the day-to-day necessities for residents such as groceries, shopping, doctors' offices, pharmacies, and restaurants. Essential services are mandatory for getting residents to remain or return. Until essential goods and services are available, people will stay away. Many operate out of a single facility, which if damaged or surrounded by damage, may be unable to recover. Because they often rely more on local consumers, small businesses can be particularly devastated by prolonged recovery. Small businesses with tight profit margins are also unlikely to have any level of business continuity insurance, making even moderate disruptions

difficult to endure. Impacts to local small businesses can have a significant impact on the entire region's economy.

Large businesses have a different effect on the Bay Area economy. Large-scale enterprises can be major employers for a single city. These businesses are essential to many local economies. During a disaster, however, large national corporations, unlike small local businesses, have the capital necessary to temporarily or even permanently move their operations out of the region. In addition, The Bay Area regulatory environment, including zoning, permitting and environmental regulations may also inhibit businesses after a disaster, making it too difficult to stay or rebuild. Such an exodus can have disastrous consequences for local employment, as well as for a city or county's tax base. Whether small or large, local or national, businesses are a large part of what keeps the Bay Area thriving.

### **Critical Facilities**

Some services such as healthcare, schools, and police and fire, are crucial for the functioning of communities, especially in the immediate post disaster environment. Other essential facilities for community functioning include public buildings that house community services such as libraries, or privately owned grocery stores, gas stations, banks, parks, places of worship, and many others. Understanding where these facilities are, and which communities they serve, is crucial to understanding the consequence if they are damaged.

Directly following a disaster, first responders will be called into action. Local fire and police will be supported by mutual aid from California Highway Patrol, Coast Guard, search and rescue units, and other emergency responders. These services help limit the impact of the disaster and reduce community losses.

### **Public Facilities**

For small jurisdictions, a single facility may house all fire or police services. Larger jurisdictions may have multiple facilities, each with unique

roles. When there are multiple facilities for each department, it is important to know which functions are housed where. All facilities may be reliant on a single station's dispatch center, or one facility may house the only hazardous waste team. Understanding the services each facility is responsible for is crucial when prioritizing mitigation strategies, or when there are decisions on where new equipment or services are housed.

### **Hospitals and Health Care Facilities**

Hospitals and health care buildings are important for two reasons: they treat those injured during the hazard event, and they are housing or serving patients with specific medical needs. In a severe disaster event, there may be thousands of injuries that require immediate health care. Hospitals need to be operational to fulfill this need during the response phase of the disaster. Additionally, hospitals and other health care facilities (general practice, pharmacies, assisted living homes, etc.) must continue to support the patients they were serving before the event. Hospitals and assisted living homes cannot be evacuated like other buildings because of the detrimental impact it could have on patients. Pharmacies and non-acute care facilities must remain functional to provide those with existing health needs with necessary life-sustaining services.

In 1973, as a direct result from the 1971 Sylmar earthquake, during which a hospital collapsed, California passed the Alfred E. Alquist Hospital Seismic Safety Act, to require acute care hospitals be designed to remain standing and operational immediately after an earthquake. The law was amended after the 1994 Northridge earthquake, to include the evaluation and rating of hospital compliance with the law. All hospitals are required to be compliant with the law by 2030. This law is specific to acute care hospital buildings, and only addresses the earthquake hazard. Other health care facilities are not required to be designed or retrofit to a higher level.

### **Schools**

Schools are particularly important community assets, as residents highly value the safety and education of their children. Safe schools are

important for the safety of children inside. A functional school following a disaster is also important to continue providing educational services during a community's recovery. If they are not operational families may choose to move in order to enroll their children in school. For families that stay, parents may be unable to return to work if schools are not in session.

The important role of a school expands beyond education. Schools can be the center of a community's social fabric. They are not just a space for youth, but a place for the community as a whole. Schools are often where community meetings, performances, and events are held. Following disasters, some schools can serve as temporary shelter sites, while others might house social services to support disaster stricken communities.

While many of the critical facilities already listed may be located in publicly owned buildings, there are a number of other public services and operations that are critical for a jurisdiction to properly recover. City administrative services will be crucial to meet the surging demand for approvals, permits, and financing. Many public services outside the scope of emergency response will also need to be restored and operating soon after an event. Any social services that local governments administer will need to be restored quickly. Lastly, many local governments operate a number of infrastructure systems (local roads, water distribution, sewer, etc.) that will need departments to quickly repair damaged components and restore service to residents. Without a place to continue working, or without the resources or records needed to complete the tasks, a jurisdiction may be ill equipped to meet the increased workload expected in the aftermath of a disaster event.

### **Building Physical Vulnerability**

Some buildings are more susceptible to damage in hazard events than others. A well designed building neighboring a poorly designed building can experience the same flood level or the same degree of shaking but will have completely different outcomes. Identifying which buildings in

a community are most fragile, and what services are housed in the structure, is important for developing appropriate and actionable strategies. Many building types are uniquely fragile to individual hazard types. The specific siting and design of buildings is very important for four hazards in particular: flood, fire, earthquake, and landslide.

Many communities in the Bay Area have neighborhoods that are decades, if not a century, old. These buildings add much to a community's character but are also more likely to experience damage because they were built at a time when building codes were not as stringent as today. This section details specific types of structures that can be more susceptible to damage in different hazard events, and which building uses most commonly occupy these structure types.

### Current and Future Flooding

Almost all manufactured homes are destroyed beyond repair by flooding. Wood frame buildings are likely to receive significant damage as they are unable to withstand hydrostatic pressure and wood is vulnerable to water damage and mold which has a direct effect on indoor public health. Structures with habitable space below grade are vulnerable to sea level rise, storm events, and elevated groundwater. Essential mechanical and electrical equipment in buildings are highly water and salt sensitive, and are often located below-grade or on the ground floor.

Most residences, employment sites, and community facilities are highly susceptible to damage from sea level and groundwater rise because of their construction methods or materials. When flooding damages these structures, the release of hazardous materials including paints, cleaners, oils, batteries, pesticides, asbestos, and medical waste can occur.

### Fire

For wildland urban interface (WUI) fires, the siting of buildings relative to vegetation directly influences their susceptibility to damage. Buildings with dense vegetation near and against the

structure are at a much higher risk to damage if there is a fire. CalFIRE recommends buildings within Wildland-Urban Interface (WUI) zones have cleared vegetation in a 30' radius around the building, with sparse vegetation in a 100' radius around the building. By reducing fuel sources around the building, the fire is less likely to reach the house and fire fighters may be more able to protect the home from damage.

Buildings that have open eaves for attic ventilation or that have wood shingle roofs are especially vulnerable to fire damage. Small embers from flames far away can easily ignite in these spaces if they're not designed with fires in mind. California Building Code Chapter 7A, amended in 2009, has a list of required minimum standards for homes in State Responsible Areas or in WUI zones. The standards include the material and design of roofing, attic space, eaves, ventilation, windows, and overhanging elements (i.e. decks, bay windows, etc.).

Buildings in the urban environment are more prone to fires that start in the inside, or that grow from a fire in a neighboring structure. There are many designs that have been implemented to reduce urban fires, including fire sprinklers, which can extinguish small fires and reduce the speed at which large fires spread.

One unique fire risk is the potential for fire following an earthquake. Natural gas pipelines that connect at the street may break, or gas appliances in the house that shift or fall may also break gas lines. Gas fires, or those caused by electric failures, may produce more ignitions than fire fighters have resources to respond with. Some jurisdictions have required automatic gas shut off valves be placed on the street to reduce this risk, and improvements to the building code to reduce regular urban fire risk (i.e. sprinklers) have the potential to reduce the impact of a fire following earthquake.

### Earthquake Ground Shaking

In general, ground shaking impacts buildings by exerting lateral forces on a building. Buildings are primarily structurally designed to withstand vertical

force (gravity) but may not be able to withstand lateral forces as well. This is particularly true for older buildings that were built before building codes recognized the types of forces that ground shaking exerts on buildings. However, depending on the building construction type, the way that the building responds to lateral forces differs. In the Bay Area, there are several older building types that have been identified as particularly vulnerable to ground shaking. The most common of these building types are described below.

Older (usually pre-WWII) single family homes, or previously single family homes converted into multi-family duplexes or small businesses, are often not properly bolted to their foundations and lack adequate bracing on the wood framed exterior walls enclosing the crawl space (**cripple wall**). A cripple wall is usually indicated by the presence of a crawl space below the home and/or stairs leading to the front door. These buildings can slide off their foundations or the cripple wall can collapse in an earthquake. Both damage types are extremely expensive to repair after the fact, but relatively inexpensive to retrofit before an earthquake.

In older single family homes or duplexes with an attached garage and **living space over the garage**, the open front of the garage lacks the structural support needed to support the living area above when an earthquake shakes the structure side to side. These homes may also have vulnerable cripple walls or lack foundation bolting in other areas of the house.

Multi-story buildings with large openings on the first floor, typically for parking or retail space, with residential units or office space on the upper floors may be **soft story** structures. Ground shaking causes soft story structures to sway and may cause the ground story to collapse, damaging the floors above it as well. The collapse potential is a life safety threat for tenants if the structure has not been retrofitted. In 1978 changes were made to the building code to address these deficiencies. Additional changes were made over the next 12 years. Buildings that fit the above description and built before 1978 are most vulnerable, with ranging risk for structures built from 1978 to 1990.



Single family cripple wall building



Living space house over garage



Soft story wood frame multi-unit buildings

In order to resist strong earthquake forces, concrete structures need embedded steel reinforcing bars to add ductility, or the ability to bend without breaking. Lateral movement from earthquake shaking can put too much strain on older concrete buildings lacking flexibility, pushing them past their breaking point and causing catastrophic damage. Many pre-1980 concrete structures may not contain adequate reinforcement and are a collapse risk and life safety threat in earthquakes. This type of building, **non-ductile concrete**, may be used for many purposes, but multi-family residences and offices are the most likely uses.



Non-ductile concrete buildings

A relatively cheap and fast way to build single story warehouse structures is to build concrete walls horizontally first, and then tilt them vertically. Footings and the roof are the main structural elements that then keep the walls standing. These buildings are called **tilt-ups**, and are common as warehouses, strip malls, and light industrial facilities. Many tilt-up warehouses have also been repurposed as offices, recreational facilities, and even schools or assembly buildings. Most tilt-up concrete buildings built prior to 1995 lack adequate connection between the roof and the walls. In an earthquake, the connection between the roof and the walls can fail, resulting in walls falling outward, and the roof collapsing into the building.



Concrete tilt-up buildings

Masonry buildings without steel reinforcing, often termed **unreinforced masonry** buildings (URM), may incur substantial damage including the collapse of walls and the roof. Separation may occur between the floors and the walls in an earthquake, leading to collapse of the floors and roof. URMs are often found in small commercial downtown areas with retail, office or residential spaces. Many have been used as light industrial facilities in part because of their fire resistance. Nearly all URM structures in California were built before 1933. In 1986 the State of California passed Senate Bill 547, requiring all jurisdictions in the highest seismic zone (all Bay Area jurisdictions except City of Oakley) to inventory URM buildings in their jurisdiction and establish a loss reduction program for URM structures. As a result, some cities have since adopted either voluntary or



Unreinforced masonry buildings

mandatory URM building retrofit ordinances.

Thus far the discussion has been focused on the main structure of the building. If the structure performs adequately in an earthquake, it can still be unusable after an earthquake because of non-structural damage. Chimneys, cladding, and parapets can fall off the outside of a building. Windows may break and ceiling tiles and lights may fall. Heat and cooling systems and other interior utilities may break. Broken water pipes and fire sprinklers can cause significant water damage. Fallen shelves, file cabinets, pictures, and the contents of cupboards and cabinets can create a significant mess. If these components are not properly anchored or braced, they can fall and injure people, or can be damaged, limiting the utility of the overall facility. This is especially important for facilities like hospitals with unique equipment and systems. All buildings rely on interior services that must be properly anchored and protected from other falling non-structural elements.

### Earthquake Liquefaction

Any structure in liquefaction prone areas may be susceptible to damage if the soil beneath liquefies. When soils liquefy, buildings can settle unevenly, damaging the structure and requiring extensive foundation work if the building is deemed salvageable, even if the building structure itself has been able to withstand ground shaking. In many cases of severe liquefaction, buildings with damaged foundations may require demolition and rebuilding. Single-family homes, commercial buildings under ten stories, and industrial and commercial buildings are typically built with foundations that are more vulnerable to liquefaction. However, even buildings with mat or pile foundations designed for liquefaction hazards are at risk of settlement damage. Additionally, utility connections to the building can be damaged by liquefaction, causing the building to be unusable even if it remains intact.

Damage can be more severe if the liquefaction occurs on ground that also has a slope, as the building can also slide on the slope, which was the case in San Francisco's Marina District in the

1989 Loma Prieta earthquake. Even with the only slight gradient in the Marina District, portions of the liquefaction zone moved up to two feet, which was enough to damage buildings and break utility connections.

### Landslide

Depending on the type of landslide, building design, support walls, and soil work can greatly impact the ability of a structure to resist landslide forces. For deep-seated landslides, where the earth is moving deep inside the hillside, there is very little that can be done to the structure itself. The only influence design has on the performance of the structure in those cases is if there has been extensive work to drain the water out of the soil in an effort to reduce the severity of the landslide. For smaller landslides, and general earth forces, designed retaining walls and other slope stability measures can reduce the risk of landslide conditions impacting the building.

### Tsunami

Nearly all structures in California that are exposed to tsunamis will be damaged if the tsunami is large enough. In areas with a greater threat of large tsunamis such as Japan, some structures have been specifically designed to withstand tsunami forces. This level of design is not common in California; therefore if a building is exposed to a tsunami, the design of the structure is not likely to influence its performance. Protective measures (seawalls or bay levees) can try to reduce the exposure of the tsunami, but building design in the Bay Area does not play a significant role.

### Drought

Buildings are not directly damaged by drought, but their design can contribute to the hazard. In the case of drought, buildings without low flow features and/or with water intensive landscaping will require more water to function. Buildings with water conservation designs improve the ability of a community to withstand the water supply problem presented by droughts.

## Extreme Heat

Buildings are often not directly damaged by extreme heat, but their design can contribute to the hazard. Extreme heat can be made worse if the building has poor design. For example, blacktop surrounding the building and on the roof absorb and radiate heat, making it warmer inside and around the building. Structures without passive cooling or without air conditioning may lose functionality on hot days. If a home is unable to be cooled down, residents may have to be taken to cooling centers for the duration of the extreme heat event.

## Building Functional Vulnerability

Building use can be governed by both direct damage described in the sections above, or by the interruption of necessary services. Most buildings and the uses they house are only functional if necessary infrastructure systems are also functional. If a restaurant requires electricity to cook and store food, their building may remain closed if power is out. If water and wastewater services are unavailable in a neighborhood for a length of time, people with undamaged homes may still be forced to leave until services are restored. Some critical facilities and well-prepared organizations have resources like storage or back-up generators to reduce these vulnerabilities to their building function.

## Utility & Transportation Infrastructure

Disruptions to communications, water, and transportation networks can cause emergencies to cascade into disasters. In day-to-day lives, Bay Area communities are heavily reliant on local, regional, state, and interstate utility and transportation systems. For homes and businesses to remain functional, their buildings must not only have minimal damage, but must also be connected to operating water, power, and sewer systems.

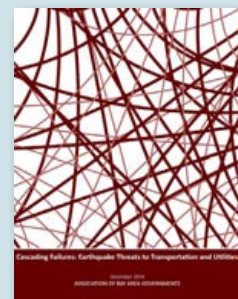
Annual outages caused by winter storms are reminders of household and business reliance

on critical infrastructure. In small emergencies, systems are disrupted for limited periods of time, or disruption is isolated to a single system, making the outage manageable for most. In large disasters, outages can last days, weeks, and months, and occur across multiple infrastructure systems at once. Because of our reliance on expansive linear systems, a single failure can impact the entire system. This type of failure can ripple and impact many more people than the hazard itself. For example, many portions of a community may not experience damage from flooding, but if flooding damages a key transportation corridor, a power substation, or sewage treatment plant, those outside of the flood zone will still be severely impacted by loss of services.

### CASCADING FAILURES – EARTHQUAKE THREATS TO TRANSPORTATION AND UTILITIES

In 2014, ABAG's Resilience Program developed a report examining the vulnerability and interconnectedness of regional transportation and utilities to earthquakes. The report produced key findings on the region's airports, ground transportation, fuel, electric, and water systems and identified how the dependencies among these systems contribute to vulnerability or provide redundancies and backups to keep utilities functioning after a major earthquake. The report supports the development of a regional Lifelines Council to further study and address critical infrastructure vulnerabilities and keep the region functioning after a disaster.

For more information visit: [http://resilience.abag.ca.gov/projects/transportation\\_utilities\\_2014](http://resilience.abag.ca.gov/projects/transportation_utilities_2014)



## Utility and Transportation Infrastructure Types

### Transportation (Roads, Rail, Air, Ports)

The Bay Area is reliant on roads, rail, and ports to connect homes, businesses, people, and goods. Roads provide routes for personal vehicles, buses, bikes, and pedestrians. Both passenger and cargo rail move passengers and freight throughout the Bay Area. Ports and airports are used for domestic and international passenger and cargo movement. Each mode of transportation is required for a functional region, and is critical during and after an event, to move people away from, and resources to, a hazard. When they are severely damaged, the inability to move people and goods will impact response to a disaster and greatly slow the recovery of the region.

At a regional level, there are multiple routes and modes that individuals can choose to get around the region. The failure of any one component within the network will have cascading impacts across other corridors and transportation modes. Corridors with no damage may become gridlocked when transportation is rerouted around a damaged area. This was seen after the Bay Bridge deck failure in the 1989 Loma Prieta earthquake. In the weeks following the earthquake, the Golden Gate Bridge experienced a record number of trips, and BART set ridership records. While this example highlights the partial redundant nature of some of the region's transportation corridors, some jurisdictions are reliant on a single mode or a single corridor that, if disrupted, will reduce the ability of residents and goods to move throughout the region.

### Fuel

Refined fuel products are used for a number of processes, with the majority going towards powering motorized vehicles (cars, trucks, buses, trains, planes, boats). Some vehicle fleets have a growing number of electric or natural gas powered vehicles; however the vast majority of vehicles are reliant on refined petroleum fuel. The interruption of the fuel sector could be brief, caused by the inability to pump gas at gas stations in the days

after an event while electric pumps are down, or could be a prolonged issue if the Bay Area fuel system is damaged.

### Natural Gas

Natural gas is used for heating and cooking in many homes and businesses, and is also supplied in large quantities for many industrial processes. Natural gas also fuels two-thirds of regionally generated electricity (ABAG, 2014). An interruption of the natural gas system could directly impact the heating of homes and businesses, and shut down dependent business sectors (restaurants and industrial facilities). As discussed in the interdependencies section, natural gas systems, as with many other utilities, are also important because they themselves can be a hazard if they are damaged. In the case of natural gas, the major fear is that a damaged pipeline leaking gas may ignite, which can spread to nearby homes and businesses.

### Electricity

Nearly all water, wastewater and communications utilities, transportation systems, homes, and business rely on electricity to function. Many critical facilities have backup electric generators to provide power in the case of electrical outages, as do a growing number of businesses and homes. These backup generators are reliant on access to fuel, should the electrical outage last longer than the stored fuel supply. Some of these fuel supplies can be located at some distance, and may not be accessible when needed. Home and businesses without backup power will remain in the dark and all electronics (refrigerators, electric heating and cooling systems, computers, etc.) will remain off.

### Water

Water is critical for basic survival and sanitation. It is also needed for agriculture, and many industrial processes. Emergency supplies, stored by both individuals and emergency management agencies, will likely only be enough for drinking needs in the immediate aftermath of an event. Sanitation, agricultural, and industrial uses of water will

require the functioning of the water system to return to service.

## Wastewater

Wastewater services are typically provided at the sub-regional and local level in the Bay Area. Most of the wastewater treatment facilities are located along the Bay shoreline, because the majority of the systems are gravity fed, and all of them discharge to the Bay. Depending on where the system is disrupted there could be either a complete loss of service, a partial loss of service, or a spill or discharge of untreated or partially treated wastewater. This can become a public health issue, requiring special actions be taken to contain and then clean up the discharge.

## Solid Waste

After a disaster, damage to buildings and utilities will result in a huge amount of waste material that must be sorted and recycled or disposed of. Individual homes and businesses are likely to have additional waste removal needs, as will jurisdictions struggling to clear debris. Debris removal will be needed to make roads passable, and to allow for more rapid repairs and reconstruction in areas with damaged and destroyed properties and infrastructure.

## Utility and Transportation Physical Vulnerability

Natural hazards can cause direct damage to infrastructure components. Because most infrastructure systems are organized as a system, a single failure can result in a system outage (i.e. if a single portion of pipeline breaks, the remainder of the system may be unusable). Additionally, the failure of one system can also impact other systems all together (i.e. if an electrical outage causes water pumps to fail). Regardless of the hazard type, linear components of different asset classes often perform similarly (i.e. in an area with liquefaction or landslides roads, rail, pipelines, and cables may all be severed by the hazard). In some cases, linear components have undergone unique improvements (i.e. waterproofing, increased

flexibility at fault crossings) that make them less susceptible than the average infrastructure component. Different fixed asset components, such as substations, generation facilities, treatment plants, transit stations, or pumping stations, can also have similar challenges. For example, most have fragile mechanical or electrical equipment below grade, or have above ground structures with similar vulnerabilities as those mentioned in the buildings section.

## Current and Future Flooding

Flooding can impact infrastructure in a number of ways, including getting non-waterproof elements wet, exposing corrodible elements to salt water, filling elements with water, and causing scour and erosion. Although some below-ground, and even at-grade, infrastructure is designed to be wet, most elements cannot be submerged in water and many cannot get wet at all. Underground infrastructure, and particularly pipelines, can float if flooded when more buoyant than water. If floodwaters are saline, such as with inundation from the bay, infrastructure elements that are not corrosion-resistant can be damaged beyond repair. In addition, the energy of strong water flows can scour and erode, damaging and destroying infrastructure elements. Bridge abutments in particular can be damaged if water, wind, wave, or tidal energy erodes the soil surrounding the structure. Other infrastructural elements that become exposed as soil erodes around them may be damaged by moving floodwaters.

Sea level rise will increase the likelihood that infrastructure elements are exposed to the impacts of flooding during storm events. In addition, sea level rise will begin to cause “sunny day flooding” in particular affecting infrastructure that relies on belowground systems that are often gravity drained or have limited pumping capacity, such as stormwater and wastewater systems. For example, most wastewater facilities in the Bay Area are built along the Bay shoreline as they discharge treated wastewater to a deep Bay location. As sea level rises some of these wastewater treatment plants will not have the same ability to discharge into the Bay, and will be required to

increase either flow storage or pumping capacity. Stormwater collection and conveyance facilities will lose capacity both as the Bay and groundwater levels rise, and backups at higher than current high tides will cause street, basement, and parking lot flooding.

## Fire

Fire can impact any infrastructure element. Depending on the intensity of the fire, underground components may be more protected than those on the surface or attached to poles. For above ground facilities, vulnerability is very similar to buildings, with the added damage potential from smoke which can affect sensitive electrical equipment used to operate infrastructure systems. Fuel and natural gas infrastructure systems are especially important to consider because of their own flammability that could contribute to the fire hazard, and the ability of fire crews to extinguish the fires.

## Earthquake Ground Shaking

Ground shaking is typically less damaging to linear infrastructure pipelines, cables, and at-grade roadways than other earthquake hazards such as liquefaction. It is the nodes of infrastructure systems that are often damaged by earthquake shaking. Just as with buildings, above ground facilities (refineries, water treatment stations, pumping stations, power plants, train stations) can all be damaged by the strong accelerations experienced in earthquakes. These facilities can also be damaged by liquefaction or fault rupture.

## Earthquake Liquefaction & Fault Rupture

Earthquakes are particularly damaging to infrastructure systems, especially when surface fault rupture and liquefaction occur. Underground pipelines, cables, and other linear elements can be broken by the ground displacement caused by liquefaction. This is especially pronounced in the transition area between zones that liquefied and those that did not, resulting in differential movement, as well as in locations of lateral spreading where pipes and other underground

elements can be pulled apart by the ground settling or sliding down a slope. Areas where pipelines cross river channels are vulnerable because these areas are often the most prone to liquefaction, and lateral spreading.

Pipelines that are more buoyant than the soil can also rise out of the ground as a result of liquefaction. In past earthquakes, sewer pipelines can raise multiple feet while the soil liquefies, resulting in severe damage to the pipe, as well as to the roadway above where manholes stick up feet above the road.

Infrastructure elements like roadways, rail, cables, and pipelines that are at the surface are also vulnerable to the displacement that can occur from liquefaction. For above-ground components, breaks are easier to find, and are often an easier fix. Above-ground lines routed along poles can be damaged if the poles fall over; however, this is rare except in severe cases of liquefaction or fault rupture.

## Landslides

Landslides, whether caused by an earthquake or by rainfall, can be very damaging to infrastructure. Regardless of the type of asset component affected, landslides can damage an entire system. Elements that cross where the slide occurred may be difficult to restore because the hillside may remain unstable for some time (especially in the case of rainfall induced landslides). Elements that became buried by the slide may also be difficult to restore if the slide area is unsafe to work around, but if the hillside is stable, may be quickly restored by simply removing debris from the asset if the debris has not caused damage to the asset.

## Tsunami

In many ways, tsunami impacts to infrastructure are similar to those due to flood, only the impact may include greater current forces as the water inundates and then recedes rapidly. These forces are especially strong along stream channels and in marinas with small inlets. Historically, tsunamis have been particularly damaging to marinas because they often create strong current flows,

which can cause boats to be thrown about, which may then damage the marina infrastructure as well.

### Drought

Drought has a direct impact on the amount of available water in the region. It indirectly influences the portfolio of energy generation available to the state, as many reservoirs are also hydroelectric facilities that produce a share of the region's power. With less water passing through these facilities, there is less electricity generated. Subsidence caused by drought can also change the elevation of the ground which may cause surface cracks on roadways that pass over areas of subsidence, but may also influence how gravity fed systems (water and sewer) operate if the subsidence is significant.

### Utility and Transportation Infrastructure Functional Vulnerabilities

Interdependence is often the term used to describe functional vulnerabilities between systems. Infrastructure interdependence is the interaction of one system on another and is used to describe a number of different interactions. The interaction between systems can result in cascading outages or failures, where the outage of one system results in loss of service for another (i.e. a cell tower that is not damaged cannot provide service because it lost electricity, and remains out of service until electricity is brought back online.) The failure of one system can also result in damage to another because of collocation (i.e. a water main break causes damage to a nearby sewer line, gas line, and the roadway above), or by an inability of systems to safely shut down in an outage (i.e. a failure caused by a hazard at one electric substation creates a surge elsewhere in the system, damaging components at a substation not exposed to the hazard). The failure of systems can also make the restoration of other systems more difficult. If roads are damaged by a landslide, it may be difficult for repair crews to get to the site of other damaged infrastructure, delaying the system restoration.

## Natural Resources

The majority of the region, and even some of the most developed areas, provide natural resources that support the regional economy, environmental quality, and quality of life. Coastal and marsh resources line the ocean and bay, and agriculture, rangeland, and forests cover the region's valleys, foothills, and mountains. These resources are critical for ecological health, habitat, recreation, and the economy. Many of the natural systems have been resilient to historic shocks, but are threatened by permanent changes in temperature, precipitation, and sea level.

The elements that make up this section were drawn from five resources: *Adapting To Rising Tides Portfolio* (2015), *Baylands Ecosystem Habitat Goals Science Update* (2015), *San Francisco Bay Subtidal Habitat Goals Project* (2010), *California Adaptation Planning Guide* (2012) and *Conservation Lands Network 1.0* (2011).

### Natural Resources Types

#### **Coastal and Bayland Resources (Corte Madera Baylands BCDP Paper & Baylands Goals Science Update):**

Coastal and bayland marsh resources provide a number of beneficial services, most notably flood risk reduction, water quality improvement, carbon sequestration, and biodiversity. These environmental services may be reduced if coastal and bayland resources are impacted in ways that reduce their size, function, quality, or ability to adapt to changes.

Coastal resources in the region include coastal bluffs, rocky shoreline, beaches, embayments, as well as seasonally closed estuaries and riparian corridors. Coastal shorelines provide a wide range of ecological services, from hosting diverse local habitats and plant communities to providing pupping, roosting, nesting and foraging for a wide range of wildlife moving up and down the west coast. The region's beaches and forests provide one of the major recreational and economic amenities available to its residents.

Baylands serve as a buffer between the Bay and shoreline development, and can include many diverse habitat types such as tidal wetlands, sand beaches, eelgrass and oysters beds, and others. These habitats have the potential to reduce flood risk by attenuating wave height and energy, and protecting inland coastal areas from flooding that could result from the overtopping or failure of structural shoreline protection such as levees, berms, and revetments. The amount of wave attenuation achieved by using nature-based infrastructure is in the early stages of testing and is related to site-specific conditions including depth, slope, bottom type, and presence and density of features such as vegetation, sand, rocky habitats, shellfish beds, which exert a drag force and slow the flow of water.

Tidal marshes improve water quality by trapping sediments and filtering pollutants, such as nutrients and heavy metals. Because marsh vegetation slows the flow of water, larger sediment particles and the pollutants adsorbed to them settle out and are buried in accumulating marsh sediment. Tidal marshes can also remove pollutants by microbial activity in shallow soil layers.

During photosynthesis, tidal marsh plants capture carbon dioxide from the atmosphere and convert this carbon into aboveground and belowground biomass. The lack of oxygen in saturated soils substantially slows down decomposition of belowground biomass, leading to the sequestration of carbon and development of organic rich soils. Sequestration results in less carbon in the atmosphere, helping slow the impacts of climate change.

The diversity of habitat types in the Baylands host an array of plants, invertebrates, fish, shorebirds, waterfowl, and mammal species, many of which are listed as threatened or endangered under state and federal law. Some species primarily use one habitat type, while other species move back and forth between habitat types. The habitat is crucial for commercially and recreationally important species (e.g. waterfowl and certain species of fish). Since small changes in topography can result in considerable changes in tidal

inundation, the more varied the micro topography is within a marsh and the adjacent shoreline and bay habitats, the more habitat types available for species to use and thus the higher level of biodiversity. Most young restoration marshes lack the topographic diversity that is present in historic marshes. Multiple agencies including the Coastal Conservancy are working on restoration designs that include more topographic diversity, and specific features such as high tide refugia islands.

In addition to natural resource benefits, bayland and coastal resources provide extensive recreational benefits to Bay Area residents. A broad set of shoreline parkland and protected areas, as well as an interconnected network of regional trails systems including the California Coastal Trail, the Bay Trail and the Bay Area water trail, provide a diverse and invaluable set of recreational amenities.

### Inland Resources

Inland rangelands, forests, and other habitats provide a number of benefits, most notably habitat biodiversity, watershed health, carbon sequestration and air quality, and recreation. The Bay Area's varied vegetation types, such as moist redwood forest, coastal scrub, semi-arid chaparral, and grasslands each have steep climatic gradients at multiple scales (e.g. coastal to inland, valley to mountain, north slope to south slope, and ridgetop to valley bottom) and provide a diverse habitat for Bay Area wildlife. The region is a recognized biodiversity hotspot of global significance - according to the Jepson Manual (Hickman 1993), more than 3,000 plant species occupy these varied environments, loosely organized into countless communities of local combinations of species (Sawyer et al. 2009; Thorne et al. 2009). In addition to this richness, the Bay Area is home to numerous endemic species with limited geographic ranges – sometimes only a few square miles or less. This spatially complex and dynamic vegetation mosaic is the foundation of Bay Area biodiversity (Conservation Lands Network 1.0).

The diverse habitats in the region support a diversity of animal species. Mammals, birds,

amphibians, reptiles, and invertebrates all play important roles and are important for the ecological health of vegetation in the region. Due to previous loss and fragmentation of habitat for urban, industrial, and agricultural uses, and in some cases due to hunting, a number of species are already endangered or threatened. Both threatened species and those that have adapted well to urban land uses will be potentially vulnerable to direct and indirect effects of climate changes.

Bay Area water supply is directly dependent on these natural systems. Local Bay Area watersheds are reliant on healthy and expansive natural lands that absorb, pool, and collect water. When the environment is changed, whether due to urban footprint changes or climatic changes, how water is absorbed and collected in the region may change, altering the environment and watershed health. When open space is developed for urban uses, non-permeable surfaces like asphalt roofs and paving result in increased water runoff during storms. Similar, wildfire can reduce infiltration and increase surface runoff by removing surface cover and vegetation.

The hundreds of square miles of forest and rangeland in the region capture carbon dioxide from the atmosphere and store the carbon as biomass. Vegetation is also important in filtering particulate matter out of the air and helps improve the region's air quality across the pollution type. These benefits have been incorporated in cities to improve air quality at the local level, but maintaining the natural landscapes across the region will help to ensure cleaner air in the region.

The region's creek and river systems also provide innumerable benefits and services. Many of the region's stream networks provide critical habitat for fisheries of statewide importance, and their habitat quality is highly dependent on instream and watershed health factors such as intensity of development, roads, barriers to passage, trash, and urban runoff and pollution. Stream corridors form ribbons of connected habitat within the urbanized bay region, offering some of the only migration corridors for wildlife in many locations.

In addition to natural resource benefits, inland natural resources provide extensive recreational benefits to Bay Area residents. Many residents of the Bay Area use the region's expansive trail networks as a primary form of recreation. The Bay Area Ridge Trail and its multiple connector trail systems link across the region's mountains to connect residents to nature, offering exercise, views, and mental health benefits.

## Agriculture

Agriculture is important as our source of food, but it is also an economic contributor in all nine Bay Area counties. The Bay Area agriculture industry produces billions in agricultural products. Food production, processing, distribution, waste, and support services make up 3% of the regions jobs. The greater food services sector, including restaurants, grocery stores, and bakeries represent 12% of regions 3.2 million private sector jobs.

Most of the produce consumed in the Bay Area is imported, primarily from the Central Valley, but nearly two million acres of Bay Area farms and ranches provide a local source of agricultural products. Because of the proximity of local agriculture, it has the potential to be fresher and produce fewer transportation emissions. Other agricultural management factors (pesticides, single crop farms, etc.) can contribute to the production of healthier, more sustainable food, which many consumers want to support. Agriculture and working lands can also be used to protect and utilize open space and as boundaries for urban sprawl.

## Natural Resources' Physical Vulnerabilities

Floods, fires, landslides, and drought are all projected to change. Natural resources typically are adapted to a recurring disturbance regime, such as wildfires, that, over the long term, support biodiversity. However, by changing the character of these regimes (frequency, location, and/or severity), climate change may detrimentally affect Bay Area ecosystems. Results can range from

unusually large physical changes from erosion, to pest outbreaks, to ecosystem shifts. Each of these changes can stress or eliminate native species.

### Current and Future Flooding (Baylands Goals Science Update; Vulnerability Assessment for the North-central California Coast)

Flooding impacts all natural resources, but baylands and coastal resources are particularly vulnerable to the anticipated increase in sea-level rise.

In Baylands, reductions in sediment availability, the stressors and limitations imposed by urbanization around the baylands, and other aspects of expected change are all adaptation challenges. Ultimately, the concern is that marshes and mudflats will drown, leaving only narrow, fragmented habitat patches along the shoreline. Such patches would be squeezed up against levees and seawalls with development behind them, exacerbating flooding and creating deleterious edge effects within the baylands. These impacts would be additive or synergistic with other stressors that may also increase, such as invasive species, contaminants, and reductions in freshwater inputs (Goals Project, 2015).

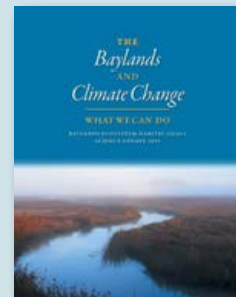
The processes that govern the extent of tidal baylands are particularly important now, given that climate change and other drivers threaten to convert a large proportion of the baylands into subtidal areas that provide different ecosystem functions and services. A number of physical processes govern the evolution of tidal baylands:

- Migration (also called transgression) is the movement of baylands upslope into their watersheds. Migration is governed by sea level, hydrology, sediment supply, plants, topography, and subsidence.
- Erosion is the loss of tidal baylands due to the loss of sediment from their surfaces or edges.
- Progradation is the growth of new baylands into the bay when subtidal areas are converted to intertidal elevations. Progradation is governed by sediment supply, intertidal plant and animal populations, and the nature of erosive forces along the boundary between tidal and subtidal areas.

### BAYLANDS GOALS UPDATE

This report is an update to the 1999 Baylands Ecosystem Habitat Goals that for the first time set comprehensive restoration goals for the San Francisco Bay estuary. It synthesizes the latest science— particularly advances in the understanding of climate change and sediment supply— and incorporates projected changes through 2100 to generate new recommendations for achieving healthy baylands ecosystems.

The habitat acreage goals set in 1999 remain the same, but recommendations have been updated—and many new nature-based infrastructure and innovative habitat restoration approaches are recommended—for the region, its major subregions, and local shorelines. These actions must be integrated with civic and economic planning to arrive at appropriate implementation strategies. This report provides technical information that policy makers and others can use in deciding how to maximize ecosystem health and long-term resiliency. For more information visit: [baylandsgoals.org](http://baylandsgoals.org)



- Drowning is the conversion of baylands to habitats lower in the tidal frame (e.g., marsh changing to mudflat or mudflat becoming subtidal).
- Accretion is the vertical buildup of marshes with inorganic sediment and organic matter (mainly peat). Accretion can prevent drowning and can convert lower tidal baylands to higher tidal baylands. For example, accretion can convert subtidal areas to tidal flats, and tidal flats to tidal marsh, as observed in many restoration projects in the bay.

On the pacific coast, sea level rise increases wave energy, and can inundate beach and dune

habitats, increasing rates of shoreline erosion and forcing the upland retreat of these habitats. Beach and dune habitats could incur a reduction in areal extent and/or an increase in fragmentation, shifting from continuous habitat to narrower, steeper, and isolated pocket beaches where man-made or natural barriers block upland retreat. Sea level rise can also disrupt successional dynamics and degrade habitat quality by preventing the formation of mature coastal dune vegetation communities (NOAA, 2015).

## Fire

While wildfire is a critical ecosystem process in much of California, climate change is expected to contribute to increases in fire frequency, size, and severity beyond the historic range of natural wildfire variability. In general, more frequent, larger, and higher-severity fires have been predicted due to increasing length of the fire season, drier fuels, and decreasing forest health. Long term shifts in climate will affect habitats' ability to recover after a fire, and are projected in many locations to result in comprehensive shifts in land cover. Permanently altered forests and rangelands place species habitat at risk, with more sensitive species placed in a higher risk. As mentioned in Section 3.4, the aftermath of severe forest fires often results in substantial erosion and debris flows which impact watersheds in the burn area. In areas with soils with clay components, intense fires can form a seal (light crust) and keep water from infiltrating into the soil.

## Earthquake Ground Shaking

Earthquake ground shaking alone is not a significant hazard for natural resources. If the shaking results in failed levees with subsequent flooding there could be flooding impacts to natural resources. Ground shaking can also affect landslide activity, below, as well as groundwater resources (springs, seeps and groundwater lenses).

## Earthquake Liquefaction

Similar to earthquake ground shaking, earthquake liquefaction is not a significant threat for natural resources. Liquefaction may change the landscape of the terrain with slumping of waterfront along the Bay and along streambeds. If coastal resources liquefy and subside it has the potential to change the composition of coastal resources. Liquefaction of levees that results in their failure can cause flooding impacts.

## Landslides

Large landslides can have cascading impacts for riverine systems, especially in ecosystems already adversely impacted by sedimentation. If the rate of landslides or coastal erosion increases, the impacts could be more devastating for fragile ecosystems. Invasive species, a particularly threatening class of non-native species, can tolerate a wide range of environmental conditions and quickly colonize new areas – particularly following a disturbance such as a landslide.

## Tsunami

Ocean and coastal resources can be damaged by tsunami impacts; a large tsunami can wash away vegetation and scour the earth as the water retreats back to the ocean. The salinity brought in by tsunami waves and the resulting deposited debris and sediment can kill vegetation after the event. Because tsunamis damage facilities and infrastructure along the shoreline, large hazardous waste spills can potentially contaminate coastal resources.

## Drought

Drought can have a severe impact across all natural resource types, and across an area greater than State of California. Substantially less water can damage or kill vegetation, can diminish or eliminate habitat for wildlife, and can

limit agricultural production. Changes in regional rainfall may also reduce the health of sensitive species reliant on typical Bay Area rainy seasons.

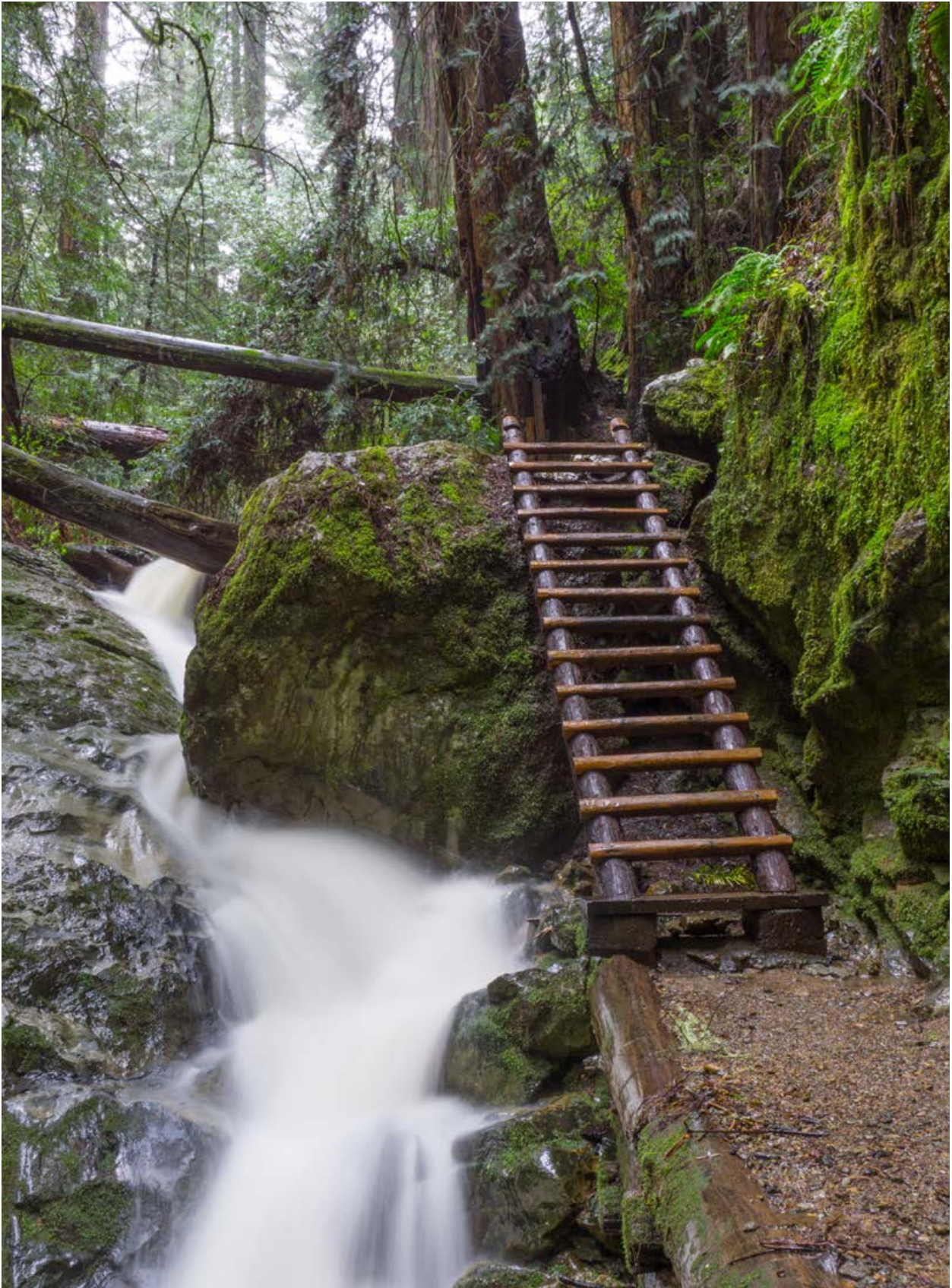
Drought can also have an extensive impact across California's agriculture sector. In severe droughts, communities with large agricultural sectors should assess secondary consequences for other businesses in the community should fields lay unproductive. These consequences could include direct and indirect employment and overall community economic security. It could also consider the public health consequence of extreme heat on the agricultural workforce.

### Natural Resources' Functional Vulnerabilities

In this section, natural resources have been described separately, but they are inherently connected systems that in turn affect multiple built resources and human communities. The health of the forests, rangeland, and agriculture fields directly influence the vitality of creeks, marshes, the Bay, and urban systems. Many solutions to improving existing health or protection may require a systems approach, where mitigating one natural resource may improve another. While tradeoffs in ecosystem management are at times necessary, in many cases multiple resources face similar stressors and threats which can be

addressed together. Similarly, strategies that support robust natural resources benefit the resilience of urban environments, providing locally available resources, buffering urban impacts, and providing cultural and spiritual value.

Because of the systemic structure of natural resources and the many benefits they afford, their protection is critical to the Bay Area's future resilience. Planning ahead of catastrophes can enable the development of nature-based flood-protection and other green infrastructure that protect and enhance human communities and natural ecosystems. Without such plans, engineered solutions that do not optimize ecosystem services and ecological functioning may be implemented after a disaster; often these solutions are implemented by agencies without a requisite ecological mission or expertise. For example, after a flood some areas of shoreline might be remediated with seawalls next to deep water. As discussed in the Baylands Habitat Goals Science Update, a solution with intertidal wetlands and subtidal habitats might offer a more optimal and durable solution for the adjacent human communities, but action is needed now to keep pace with sea level rise. As a result, continued emphasis on integrated ecological planning and connections to civic and urban planning will reduce vulnerabilities and social costs for a wide range of habitats.



# WHAT LIES AHEAD





SAKS FIFTH AVENUE

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RUN  
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## What Lies Ahead

Sections 2 and 3 are snapshots of the technical information available in the Bay Area to characterize risks and to support informed mitigation and adaptation decisions. The region has been fortunate over the past several decades to be the recipient of applied research and national pilot programs, resulting in some of the best hazard and local asset data in the country to characterize risk. While uncertainty always remains, regional decision makers have ample risk information to use to develop and implement robust mitigation and adaptation strategies. Bay Area counties, cities, and special districts can develop plans to aggressively reduce risk and build resilience.

The Bay Area has been a leader in natural hazard risk reduction for decades, financing improvements to the built environment, often with federal or state support. Past social and financial investments in risk reduction have substantially improved regional resilience. Because regional risk is dynamic, new collective efforts will be needed as regional risk conditions change while new development arises and social networks evolve.

By 2040 the region is expected to add 1.8 million new residents and 900,000 new jobs (ABAG, 2013). This growth will be supported by different land uses and intensity than exist today. However, the challenges that will arise are not new. Over the last century the Bay Area regional population grew from one to seven million, changing the built and natural landscape dramatically. Going forward, both societal systems and climate will change more rapidly and must be met with adaptive and consistent action to address the changing landscape. Regions able to integrate and expand upon capacity and resources within their communities -- from non-profit organizations to emergency responders, business owners, community members and decision makers -- will be more resilient and better able to reduce consequences of hazards to the economy, society, public health and safety, and environment. The institutions, organizations, regulations, and participation processes used in current decision-making are critical in developing the Bay Area's ability to respond to future hazards. Resilient approaches must continue to improve governance capacity to make proactive change.

Regional resilience will not be achieved by a standalone resilience plan or policy agenda. Natural hazards are a part of a much larger ecosystem and must be integrated through creative and innovative comprehensive planning. Resilience goals must be paired with economic, equity, and sustainability targets to create complete strategies that improve all dimensions. Many cities in the region are acting comprehensively to address these issues with an

integrated approach. Berkeley, Oakland, and San Francisco have all been included in the Rockefeller Foundation's 100 Resilient Cities initiative. Each city is given resources to expand their approach to resilience and integrate innovative practices throughout city policies and programs to reduce the impacts of acute shocks and chronic stresses. The Bay Area is the only area where the Rockefeller Foundation invited multiple cities within the same region to the initiative.

As part of the implementation of Plan Bay Area and with direct action by cities, East Bay Corridor Initiative partners are acting to build resilience among cities linked by a common transportation corridor. From Rodeo to Fremont, cities along the East Bay shoreline are taking a collaborative and integrative approach to address resilience, sustainability, and affordability by simultaneously improving the quality of housing through seismic upgrades, home energy and water upgrades, and acquisition/rehabilitation of at risk affordable housing. Cities are linking issues to solutions to create comprehensive improvements to the housing stock, align community infrastructure, increase opportunity, and catalyze development along the East Bay Corridor.

The Bay Area has risks that need addressing today. Using this document, local planners can shift from understanding, to solving risk problems. People responsible for our community resources -- from buildings to infrastructure systems and services -- can strengthen regional resilience with the technical guidance in the Bay Area Risk Profile document, and by connecting regionally to address problems which we've been unable to address in the past.

Disaster resilience, social equity, economic prosperity, and environmental sustainability are a shared responsibility in the San Francisco Bay Area. Engaging citizens, the private sector, and government together to address these challenges is necessary to build the broad support necessary to achieve the region's comprehensive goals.

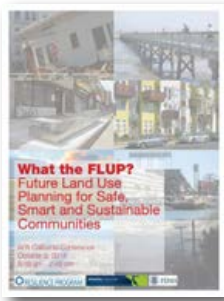
# APPENDIX





# Appendix

In addition to the information included in Risk Profile, ABAG has collected and produced a long list of resources to assist local jurisdictions with the development of hazard mitigation plans, resilience strategies, and action implementation. The additional resources described here can be found on the ABAG resilience page website: [resilience.abag.ca.gov](http://resilience.abag.ca.gov)



## Future Land Use Planning for Safe, Smart, and Sustainable Communities | APA Workshop Materials

Most of the individual resources described below were compiled into a full binder of materials for use in a one-day workshop at the 2015 APA California Conference. It contains a synthesis of process support tools, templates, and data resources to assist hazard mitigation, climate adaptation, and the integration of these fields into planning documents. This document is currently under further development by ABAG staff and should be available by the end of 2017.

*Document | pages 169 | 10-2015*

## LHMP PROCESS OVERVIEW

### Resilience planning process overview

Gives an overview of hazard mitigation, and resources a jurisdiction can use to plan out their planning process. It provides a simple crosswalk on the connections and similarities between an LHMP, Safety Element, and Climate Adaptation Plan.

*Powerpoint | 23 slides | 4-2015*

### Resilience planning process roadmap

A high level overview of a hazard mitigation and/or climate adaptation planning process. Highlights points at which local public workshops might provide input to a local planning team's process.

*Document | 1 page | 4-2015*

### LHMP Sample Outline

Provides a generic plan outline local jurisdictions can use as a starting point for their hazard mitigation or climate adaptation plan. It also provides annotations on resources a jurisdiction can use to write sections of the plan.

*Document | 4 pages | 4-2015*

### Choosing your planning team

A good planning process starts with the development of a diverse local team. This document provides a worksheet to select departments, agencies, and stakeholders you would like to include in your plan.

*Document | 4 pages | 4-2015*

## COMMUNITY ENGAGEMENT

### Community engagement strategy

Gives an introduction to community engagement. For experienced planners it provides a reminder of

the key attributes for community engagement. For staff new to community engagement it offers up strategies for building engagement in your community, including how to invite the public, how to layout a room appropriately, and some sample materials that highlight the do's and don'ts.

*Powerpoint | 72 slides | 4-2015*

### **Engaging community based organizations (CBO)**

Community based organizations can be valuable networks to tap for community engagement. This worksheet offers an organized way to think through who you might engage.

*Document | 2 pages | 4-2015*

### **What works for recruiting the public**

A one-page of bullets that can help boost your recruitment of the public to your events.

*Document | 1 page | 4-2015*

## **HAZARD AND RISK ASSESSMENTS**

### **Risk assessment process part I**

Gives a hazard identification and risk assessment process overview. Accompanies the document below.

*Powerpoint | 76 slides | 7-2015*

### **Risk assessment process part II**

A written document to accompany the presentation above. The risk assessment process is organized into five steps: (1) set community goals, (2) describe hazard, (3) determine your assessment methods, (4) conduct the assessment, (5) summarize vulnerability. The document provides both process suggestions as well as links to resources you use directly in your plan as well as worksheets to help you with your risk assessment process.

*Document | 36 pages | 7-2015*

### **Headline exercise**

If you follow the five step risk assessment process described above the headline exercise is a tool for developing mitigation goals for your community.

*Document | 2 pages | 7-2015*

### **Risk assessment scoping exercise**

Even the best resourced communities have limitations on the assessment they can perform. This brief gives you ways your planning team can scope the assessment to meet your local needs.

*Document | 2 pages | 7-2015*

### **NFIP Repetitive Flood Loss Structures Sample Request Letter**

As part of the LHMP process there is a specific requirement to include repetitive loss property information. This is a sample letter to retrieve information from the Region IX FEMA office.

*Document | 1 page | 7-2015*

### **Open Data Portal**

All the map layers in the Risk Profile report use mapping layers that are organized and available on the Resilience Program's Open Data page. The layers can be used to create maps scaled to local jurisdictions as well as for exposure analysis.

*Website | 7-2015 (with updates as needed)*

## **STRATEGY SELECTION, EVALUATION, AND IMPLEMENTATION**

### **Strategy selection, evaluation, and implementation process**

Gives a process overview of strategy selection and evaluation. A strategy worksheet and possible evaluation metrics for prioritization and organization are shared.

*Powerpoint | 49 slides | 9-2015*

### **Strategy development and implementation worksheet**

Strategies that have more substance and attributes determined ahead of time have a greater opportunity of being implemented, and provides a preliminary resource to support local funding allocation or external grant funding. The two page worksheet provides a consistent approach for describing and organizing strategies.

*Document | 2 pages | 9-2015*

### **Strategy development exercise & examples**

To support the use of the development worksheet, this exercise gives users examples of strategies and how the worksheet can be filled in.

*2 Documents | 4 pages; 2 pages | 9-2015*

### **Strategy evaluation criteria**

Once a list of strategies has been developed this spreadsheet can be used to organize actions and/or prioritize and evaluate.

*Excel Spreadsheet | 2 sheets | 9-2015*

### **Strategy source**

Many communities already have stated hazard mitigation and climate adaptation strategies in existing local documents and plans. There are regional, state, and federal resources that also provide common best practice strategies that cities can adapt for their local needs.

*Document | 4 pages | 9-2015*

## **FEMA RESOURCES**

### **FEMA Mitigation Planning Handbook**

Provides comprehensive materials for a Local Hazard Mitigation Plan, and outlines all the specific requirements to produce a FEMA approved plan. Includes an Appendix that provides a checklist of all FEMA requirements.

*Document | 162 pages | 3-2013*

### **FEMA multi-hazard mitigation planning**

Provides an overview of hazard mitigation planning and links to additional information and FEMA resources.

*Website | 2-2017*

### **FEMA Local Mitigation Plan Review Guide**

A resource to help Federal and State officials assess Local Mitigation Plans in a fair in consistent manner. This guide is used by reviewers to edit and approve local plans.

*Document | 52 pages | 1-2011*

## **FEMA Local Mitigation Plan Review Tool**

The tool provides a summary of FEMA's evaluation of whether a Local Hazard Mitigation Plan has addressed all requirements. It is the review tool that FEMA Mitigation Planners use to provide feedback to communities.

*Document | 11 pages | 1-2011*

## **Integrating the LHMP into a Community's Comprehensive Plan**

A hazard mitigation or climate adaptation plan can be integrated into a community's comprehensive plan or general plan. The resource has a how-to section, as well as best practice case studies from communities in FEMA Region X in the Pacific Northwest.

*Document | 64 pages | 2013*

## **Plan Integration: Linking Local Planning Efforts**

All the map layers in the Risk Profile report use mapping layers that are organized and available on the Resilience Program's Open Data page. The layers can be used to create maps scaled to local jurisdictions as well as for exposure analysis.

*Document | 126 pages | 7-2015*

## **ADDITIONAL RESOURCES**

### **2011 Local Hazard Mitigation Plan adopted by ABAG**

The Local Hazard Mitigation Plan process that ABAG led in 2010 and 2011 is available on the Resilience Program Website. The now expired plan and all appendices are on the website as well as links to local jurisdiction annexes.

*Website | 2015*

### **State of California Hazard Mitigation Plan**

In 2013 California updated the State Hazard Mitigation Plan. The 2013 document is a 875 page document. The website has links to previous State Plans as well as additional hazard mitigation planning guidance.

*Website | 2013*

### **City of Baltimore Combined All Hazards and Climate Adaptation Plan**

Best practices in hazard mitigation can be found across the United States. City of Baltimore's plan has been a commonly cited best practice for other cities to look toward.

*Website | 2013*

### **City of Berkeley Local Hazard Mitigation Plan**

The City of Berkeley was one of the first cities to adopt a Local Hazard Mitigation Plan 15 years ago. The City's 2014 update offers a best practice document for others within the same region to look to for ideas that might be easily adapted for their plans.

*Document | 248 pages | 6-2014*

### **Monterey County Multi-Jurisdictional Hazard Mitigation Plan**

Many counties lead a multi-jurisdictional planning process with city annexes onto the Plan. Monterey County offers one example of how the cities and the county worked together to produce a multi-jurisdictional plan.

*Document | 101 pages | 9-2014*

### **CalOES hazard mitigation web portal**

The State offers additional resources to help communities with hazard mitigation planning. The website links to a hazard map viewer, specific grant program assistance, and information on specific natural hazards.

*Website | 2015*

### **Hazard Mitigation: Integrating Best Practices into Planning (APA)**

The American Planning Association released a report on best practices for integrating hazard mitigation into the urban planning field. The document provides background on hazard mitigation in planning as well as case studies of small, medium, and large cities that have integrated hazard mitigation into their planning documents.

*Document | 156 pages | 5-2010*



# Association of Bay Area Governments

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