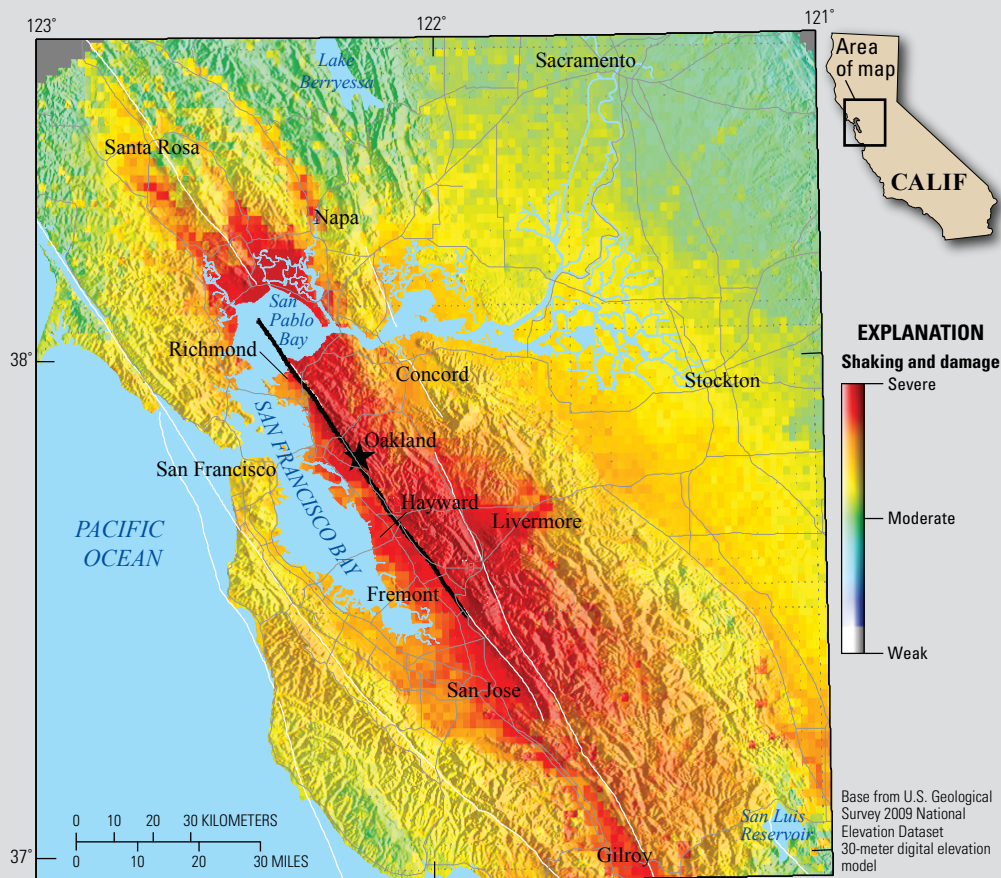


The HayWired Earthquake Scenario— **WE CAN OUTSMART DISASTER**

The HayWired earthquake scenario, led by the U.S. Geological Survey (USGS), anticipates the impacts of a hypothetical magnitude-7.0 earthquake on the Hayward Fault. The fault is along the east side of California's San Francisco Bay and is among the most active and dangerous in the United States, because it runs through a densely urbanized and interconnected region. One way to learn about a large earthquake without experiencing it is to conduct a scientifically realistic scenario. The USGS and its partners in the HayWired Coalition and the HayWired Campaign are working to energize residents and businesses to engage in ongoing and new efforts to prepare the region for such a future earthquake.



This map of the San Francisco Bay region, California, shows simulated ground shaking caused by the hypothetical magnitude-7.0 mainshock of the HayWired earthquake scenario on the Hayward Fault. Red shows the most extreme ground shaking and where damage is the worst. The mainshock begins beneath the City of Oakland (star) and causes the Hayward Fault to rupture along about 52 miles of its length (thick black line). White lines are other major faults in the region.

The U.S. Geological Survey (USGS) is leading the HayWired earthquake scenario, which examines the likely effects of a large earthquake in California's San Francisco Bay region. This hypothetical earthquake is only one of many plausible events that could be the region's next big earthquake. The name HayWired speaks to the threat of earthquakes on the Hayward Fault and the vulnerabilities and strengths posed by the interconnectedness of the bay region's people, utilities, roads, and economy—including the digital economy.

The HayWired scenario anticipates the impacts of a hypothetical magnitude (M) 7.0 earthquake (mainshock) and its aftershocks on the Hayward Fault. The fault is along the east-bay side of San Francisco Bay and is among the most active and dangerous in the United States, because it runs through a densely urbanized and interconnected region with a population of more than 7 million people. A scientifically realistic scenario is one

way to learn about a large earthquake without the people of the bay region actually living through a disaster.

The HayWired scenario was developed to guide residents of the bay region and policymakers in earthquake-risk reduction and resilience-building actions. Such actions taken now, before an earthquake, will help reduce injuries, damage and losses to buildings and infrastructure, and the number of people displaced from their homes, shortening the bay region's recovery time when the next earthquake occurs.

The first HayWired earthquake scenario report was published in April 2017 (when released, these reports are made available at <https://doi.org/10.3133/sir20175013>). Since then, the USGS and its partners in the HayWired Coalition and the HayWired Campaign have been working to help residents, businesses, and local governments become better prepared for a future earthquake. **Together, we can outsmart disaster!**

A Certain Future of Large Earthquakes

The threat of a future earthquake as described in the HayWired scenario is real and could happen at any time. Scientists have documented a series of major prehistoric earthquakes on the Hayward Fault, approximately one every 100 to 220 years during the past 1,900 years. On average, for the past 12 major earthquakes on the fault, the interval between events has been about 150 years plus or minus 60 years. The last major earthquake on the Hayward Fault was a magnitude-6.8 earthquake in 1868—150 years ago . . .

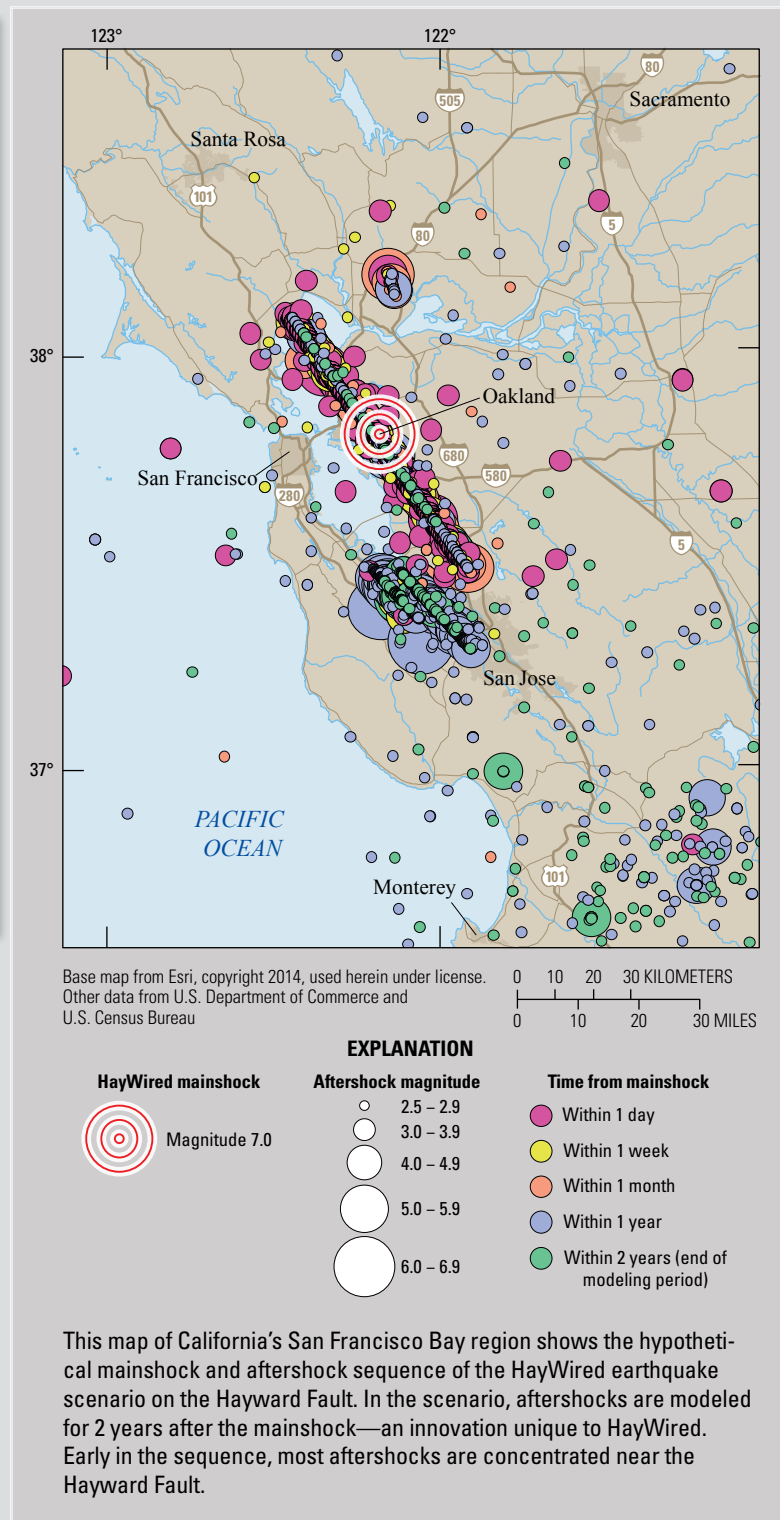


(Photograph of 1868 Hayward Fault earthquake damage; courtesy of California State Library.)

Hazards from the Mainshock and Aftershocks

The epicenter of the hypothetical $M7.0$ mainshock of the HayWired scenario is set on the Hayward Fault beneath the east-bay city of Oakland. In the scenario, the earthquake is assumed to occur at 4:18 p.m. on April 18, 2018, the anniversary of the $M7.8$ 1906 San Francisco earthquake. The mainshock ruptures the fault along its length for about 52 miles.

East-bay cities along the corridor from Richmond in the north to Fremont in the south—including Berkeley, Oakland, San Leandro, and Hayward—are hardest hit by violent ground shaking and sudden fault offset. This offset, movement of opposite sides of the fault relative to each other, is more than 6 feet in some places. Slow offset (afterslip) along the fault will continue for several months. Strong shaking is felt throughout the San Francisco Bay region. Shaking causes liquefaction (soils becoming liquid-like) in sandy, water-saturated soils along the margin of San Francisco Bay and along streams. It also causes landslides in the hills and mountains surrounding the bay, especially the hills of the east bay. Many aftershocks occur in the minutes to years following the mainshock, with the largest ($M6.4$) occurring in Santa Clara County, near San Jose.



These hazards are described in detail in the HayWired scenario. They provide a basis for understanding building damages, water-supply disruptions, and fires that could result from a $M7.0$ earthquake on the Hayward Fault.

HayWired Coalition Partners

ALAMEDA COUNTY MAYORS' CONFERENCE • ALAMEDA COUNTY Sheriff's Office, Office of Emergency Services • AMERICAN Red Cross • ART CENTER College of Design • BAY PLANNING COALITION • BOSTON UNIVERSITY • BUSINESS RECOVERY MANAGERS ASSOCIATION • CALIFORNIA BUSINESS, CONSUMER & ECONOMIC DEVELOPMENT • CALIFORNIA GOVERNOR'S OFFICE OF EMERGENCY SERVICES • CALIFORNIA INDEPENDENT OIL MARKETERS ASSOCIATION • CALIFORNIA ISO • CITY OF OAKLAND, FIRE DEPARTMENT • CITY OF SAN FRANCISCO, DEPARTMENT OF EMERGENCY MANAGEMENT • CITY OF WALNUT CREEK • CONTRA COSTA COUNTY MAYORS' CONFERENCE • MMI ENGINEERING • OFFICE OF THE MAYOR, CITY AND COUNTY OF SAN FRANCISCO • PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER • PACIFIC GROUNDWATER CENTER • SPA Risk LLC • SPUR • STRATEGIC ECONOMICS • STRUCTURAL ENGINEERS ASSOCIATION OF NORTHERN CALIFORNIA • THE BRASHEAR GROUP

Building Damages

The Hayward Fault runs beneath the foundations of more than 300 buildings and other structures. One such building, the University of California Berkeley's Memorial Stadium, is nearly bisected by the fault and has been retrofitted to withstand shaking and fault offset. Earthquake hazards from the fault are a threat to approximately 2 million buildings in the San Francisco Bay region.

For the HayWired scenario, property damage and direct business disruption losses are estimated to be more than \$82 billion (in 2016 dollars). Most of the losses are attributable to shaking damage, liquefaction, and landslides (in that order). Eighty percent of shaking damage is caused by the *M*7.0 mainshock, and the rest is due to aftershocks over a 2-year period.

Studies done for the HayWired scenario show that:

- Damage from the mainshock could render older steel-frame high-rise office buildings and newer reinforced-concrete residential buildings in downtown Oakland and San Francisco unusable for as long as 10 months.
- Damage from the mainshock could displace about 77,000 households, and if other factors (such as utility outages) are included, the damage could displace as many as 152,000 households or approximately 411,000 people (based on 2000 U.S. Census data).
- Even if all buildings in the bay region met current building code, 0.4 percent could collapse, 5 percent could be unsafe to occupy, and 19 percent could have restricted use.
- For only a small percentage cost increase, more resilient buildings constructed to more stringent building codes could allow 95 percent of the bay region's population to remain in their homes and workplaces following such an earthquake.
- When the public is consulted, they express a preference and willingness to pay for greater building resilience.

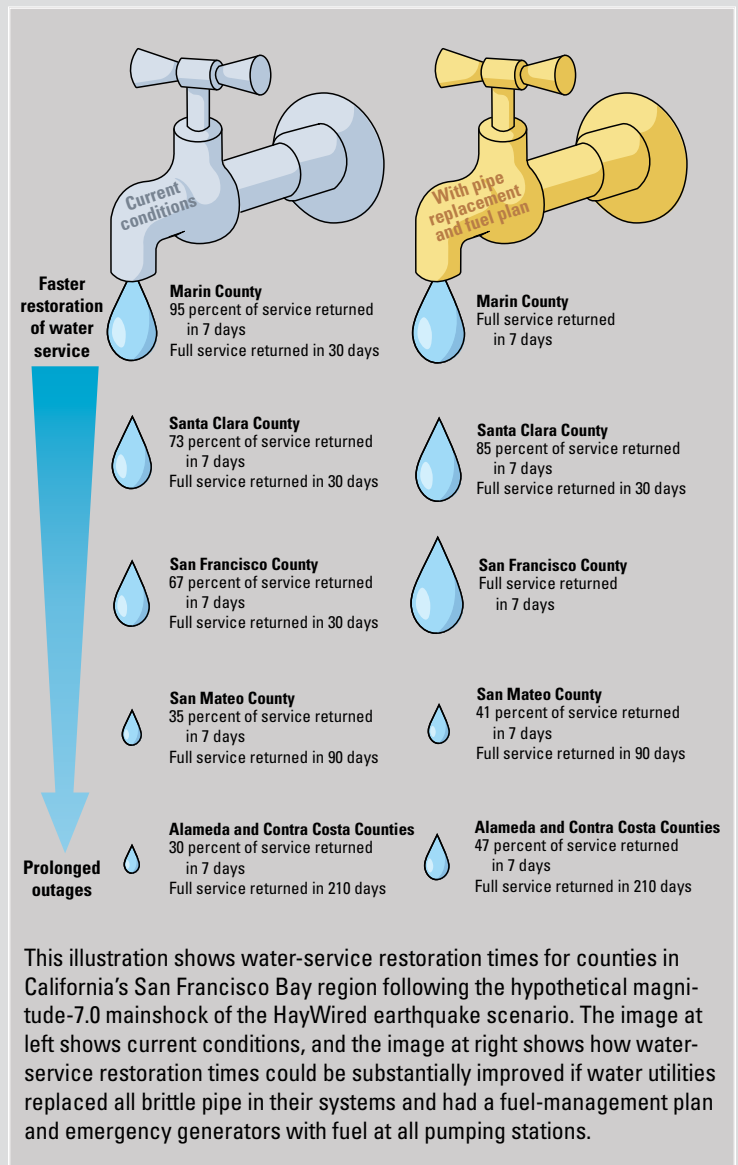
Casualties and Trapped People

For the HayWired scenario mainshock, estimates of casualties in the San Francisco Bay region include 800 deaths and 18,000 nonfatal injuries from building and structural damage caused by ground shaking and liquefaction hazards. More than 2,500 people in the region could require rescue from collapsed buildings, and more than 22,000 people could require rescue from stalled elevators. A study done for the scenario suggests that if an earthquake early warning system (ShakeAlert) were fully implemented for the bay region, and if people heeded alerts to promptly use "Drop, Cover, and Hold On" actions to protect themselves, as many as 1,500 of the 18,000 nonfatal injuries from the mainshock could be prevented.

Damages to Water Supply

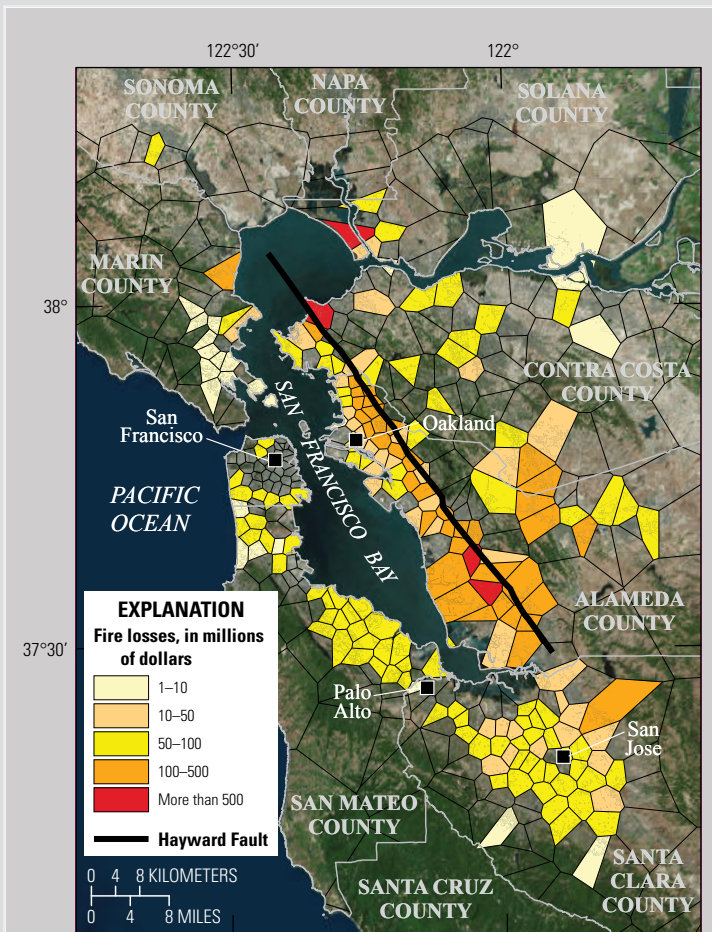
As shown in recent large earthquakes worldwide, older, brittle pipes in water-distribution systems that supply homes and workplaces are vulnerable to damage. Restoration time depends on the restoration of other utilities and transportation routes and the availability of labor and material resources.

For the HayWired mainshock and aftershocks, a new water-network resilience model is used to estimate damage to and restoration times for two water networks in the San Francisco Bay region. Water-supply restoration times are also estimated for bay-region counties. Water-distribution systems in most of the bay region would be affected, but east-bay residents could lose water service for 6 weeks (some for as long as 6 months). Not only would normal water service be restricted, but the ability to suppress fires would also be reduced.



Fire Following Earthquake

Damage from the HayWired mainshock could trigger widespread fires in the San Francisco Bay region. During and soon after the mainshock, more than 400 gas- and electric-related fires could ignite. These fires could form conflagrations that might be as destructive as the powerful ground shaking of the mainshock. For example, the 1991 East Bay Hills firestorm killed 25 people, destroyed more than 3,000 homes and 450 apartment units, and burned more than 1,500 acres.



Data from C. Scawthorne, SPA Risk, LLC. Image compiled by M. Germeraad, Association of Bay Area Governments—Metropolitan Transportation Commission. Base image from Google Earth. County lines from Esri, copyright 2014, used herein under license

This map of California's San Francisco Bay region shows areas burned as a result of fires caused by the hypothetical magnitude-7.0 mainshock of the HayWired earthquake scenario on the Hayward Fault. Warmer colors show areas with greater building losses. Effects are most severe near the Hayward Fault itself. These fires would result in a loss of residential and commercial building floor area, equivalent to more than 52,000 single-family homes. The fires following the mainshock would be directly responsible for the loss of hundreds of lives, a total building replacement value of almost \$16 billion, and total property losses approaching \$30 billion (2016 dollars). Areas (polygons) shown are based on distance to the closest fire station.

In the HayWired scenario, residential and commercial building space equivalent to more than 52,000 single-family homes could burn as a result of more fires than can be fought by available firefighters and fire trucks. This is compounded by delays in response caused by communication outages, road closures and traffic, and water shortages. Such fires would kill hundreds of people, displace many more people from their homes, and cause additional property losses approaching \$30 billion (in 2016 dollars), permanently changing the urban landscape of the bay region.

Seismic retrofitting of buildings would help to reduce fire ignitions. A workshop in 2014 with bay-region firefighters also highlighted the need to coordinate with water utilities, and a first-ever joint exercise of portable firefighting water-supply systems was also conducted as part of this HayWired Coalition activity.

Ongoing HayWired Topics

The HayWired scenario team is building on engineering analyses to further explore the societal consequences of a $M7.0$ earthquake on the Hayward Fault. These societal issues include:

- Impacts on information and communications technology (the “wired” in HayWired), especially given the relevance of Silicon Valley and the technology industry to the San Francisco Bay region’s and the Nation’s economies.
- Risks to infrastructure such as lifelines (highways, the Bay Area Rapid Transit Authority (BART) system, telecommunications, and electric power), including interactions among some systems and some estimates of damage and restoration times.
- Issues for community recovery, including population displacement, social vulnerability, and challenges such as housing, financing for rebuilding and other needs, and long-term recovery planning.
- Effects on jobs and the regional economy.
- Benefits of ShakeAlert earthquake early warning.

Investing in Earthquake Safety

Preparing for the next large, damaging earthquake in the San Francisco Bay region is not an insurmountable task. Local governments, regional agencies, infrastructure managers and utility-service providers, businesses, and residents have all taken enormous strides toward the goal of a resilient bay region. The last major Hayward Fault earthquake in 1868 ($M6.8$), along with the $M7.8$ 1906 San Francisco and the $M6.9$ 1989 Loma Prieta earthquakes, motivated residents of the bay region to implement seismic-safety measures throughout local communities.

HayWired Uses Innovative Science

The HayWired scenario uses new, innovative science to better understand earthquake-related hazards and damages, as well as the benefits of risk-reduction actions. This science helps to:

Understand the Hazards

- More accurately predict ground-shaking intensity throughout the San Francisco Bay region using computer simulations of the way seismic waves travel.
- Pinpoint high-hazard areas using probabilities of landslide and soil liquefaction triggered by earthquake shaking.
- Develop a plan to communicate forecasts of a potential aftershock sequence after a large earthquake.
- Project possible continued surface offsets along a fault after a large earthquake.

Estimate Damage and Its Effects

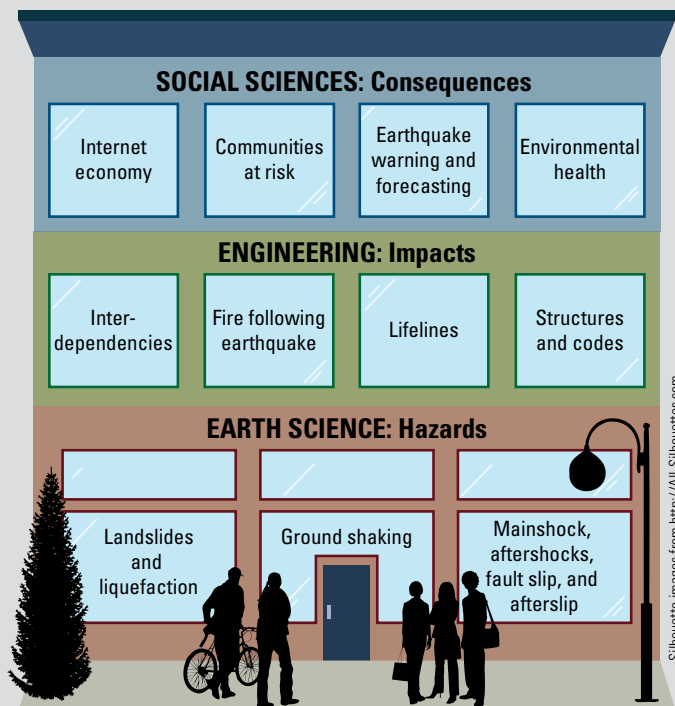
- Estimate building damages from shaking, liquefaction, and landslides, as well as additional building damage due to ongoing aftershocks.

- Understand likely damage to water-supply networks and the vital ways in which lifelines (for example, utilities and roads) are interconnected and depend on one another.
- Provide insights into additional substantial damages from fire following earthquake.
- Predict how many people could be trapped under collapsed buildings or stuck in stalled elevators.

Analyze Benefits of Risk Reduction

- Show that if old, brittle pipes are replaced beforehand and repair crews have a back-up fuel plan, water service—including drinking water—is restored faster after an earthquake.
- Demonstrate that enhancing building codes would help to reduce damage to new buildings during strong shaking.
- Better understand what the public expects from building codes, including that buildings will be useable after an earthquake.
- Emphasize that using ShakeAlert (<https://www.shakealert.org>) earthquake early warning, combined with drills to practice “Drop, Cover, and Hold On,” could help prevent thousands of injuries and save lives in a powerful earthquake.

Integrating across disciplines...



As illustrated in this diagram, the HayWired scenario is an interdisciplinary approach to understanding the effects of a powerful earthquake on a densely populated metropolitan region—California’s San Francisco Bay region. This scientifically realistic scenario builds on innovative earthquake science to examine engineering-related impacts to buildings and lifelines (utilities, communication lines, and roads), as well social and economic consequences. The insights gained from the scenario support the development of public policy that improves earthquake preparedness and emergency response not only in the bay region but also in other similarly earthquake-prone areas.

In the nearly 30 years since the Loma Prieta earthquake, the bay region has invested at least \$25 billion, and possibly as much as \$50 billion, in earthquake countermeasures (as reported in 2014 by the Association of Bay Area Governments and KQED Science; see chapter A of USGS Scientific Investigations Report 2017–5013). Cities and utilities have invested tens of billions of dollars in seismic upgrades, retrofits, and replacements of older buildings and infrastructure. However, the HayWired earthquake scenario shows that there is still more to be done.

The HayWired Coalition

Since 2014, the USGS has worked on the HayWired scenario with representatives of organizations in the San Francisco Bay region. These have included 80 fire-department chiefs, dozens of emergency managers, and many representatives from utilities (water, gas, and electric), transportation agencies, and the information technology industry.

Starting in 2016, these and new partnerships were formalized under the banner of the HayWired Coalition (see bottom of pages 2, 3, and 4). The coalition is an alliance of more than 50 agencies and businesses that aim to communicate the scenario to their constituents and address community concerns by:

- Helping to build community capacity to respond to and recover from earthquakes,
- Advancing basic knowledge of earthquake risks,
- Informing actions to reduce earthquake risks, and
- Improving the communication and use of earthquake-hazard science in decision-making.

The HayWired Coalition has completed a year of engagement through workshops, meetings, trainings, and exercises. Key members of the coalition have used the earthquake scenario to:

- Explore applications of ground-motion simulations,
- Discuss the cost and performance trade-offs of more stringent building codes,
- Examine lifeline and infrastructure interdependencies,
- Provide the details and context for a toxic chemical plume, which could be released as a result of earthquake damage, for use in a response exercise with public health-care agencies and hospitals,
- Delve into impacts to and resilience of the information and communications technology sector and its users,
- Encourage businesses to develop and share earthquake-recovery plans that consider issues of workplace damage and usability and employee issues,
- Engage city governments to better understand and address earthquake hazards and damages with respect to recovery challenges, and
- Help regional governments and other organizations bolster their development policies to better address seismic resistance of homes, as well as housing availability and financing to rebuild after a disaster.

The HayWired Campaign

The HayWired Campaign is led by the California Seismic Safety Commission and the California Business, Consumer Services, and Housing Agency. The motto of the campaign is “together, we can outsmart disaster,” serving as a call to action for statewide engagement to strengthen business and lifeline resilience and to reduce risk from an earthquake like that modeled in the HayWired scenario. The Outsmart Disaster website (<https://outsmartdisaster.com>) provides actionable science for making informed decisions and is intended to help people and businesses reduce risk and improve their safety, security, and economic well-being before an earthquake.



The Alameda County Water District, California, has improved the reliability of their water system by replacing aging large-diameter water pipes where they cross the Hayward Fault. The pipes have been retrofitted to accommodate the slow, constant creep of the fault and sudden ground shaking from earthquakes. These pipelines are only one of many such examples of lifelines (such as utilities, communication lines, and roads) and other infrastructure that cross the fault. (Photograph courtesy of McGuire and Hester.)

Additional Resources

The HayWired Earthquake Scenario

(U.S. Geological Survey Scientific Investigations Report 2017–5013)

<https://doi.org/10.3133/sir20175013>

The HayWired Scenario: An Urban Earthquake in a Connected World

(U.S. Geological Survey geonarrative with interactive content)

<https://www.usgs.gov/haywiredvol1geonarrative/>

M6.8 October 21, 1868 Hayward Fault Earthquake

(U.S. Geological Survey website with links to additional resources)

<https://earthquake.usgs.gov/earthquakes/events/1868calif/>

The Hayward Fault—Is It Due for a Repeat of the Powerful 1868 Earthquake?

(U.S. Geological Survey Fact Sheet 2008–3019)

<https://pubs.usgs.gov/fs/2008/3019/>

Earthquake outlook for the San Francisco Bay region 2014–2043

(U.S. Geological Survey Fact Sheet 2016–3020)

<https://doi.org/10.3133/fs20163020>

Outsmart Disaster

(California Seismic Safety Commission and California Business, Consumer Services, and Housing Agency statewide campaign website)

<https://outsmartdisaster.com>

Seven Steps to Earthquake Safety

(Earthquake Country Alliance website)

<https://www.earthquakecountry.org/sevensteps/>

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