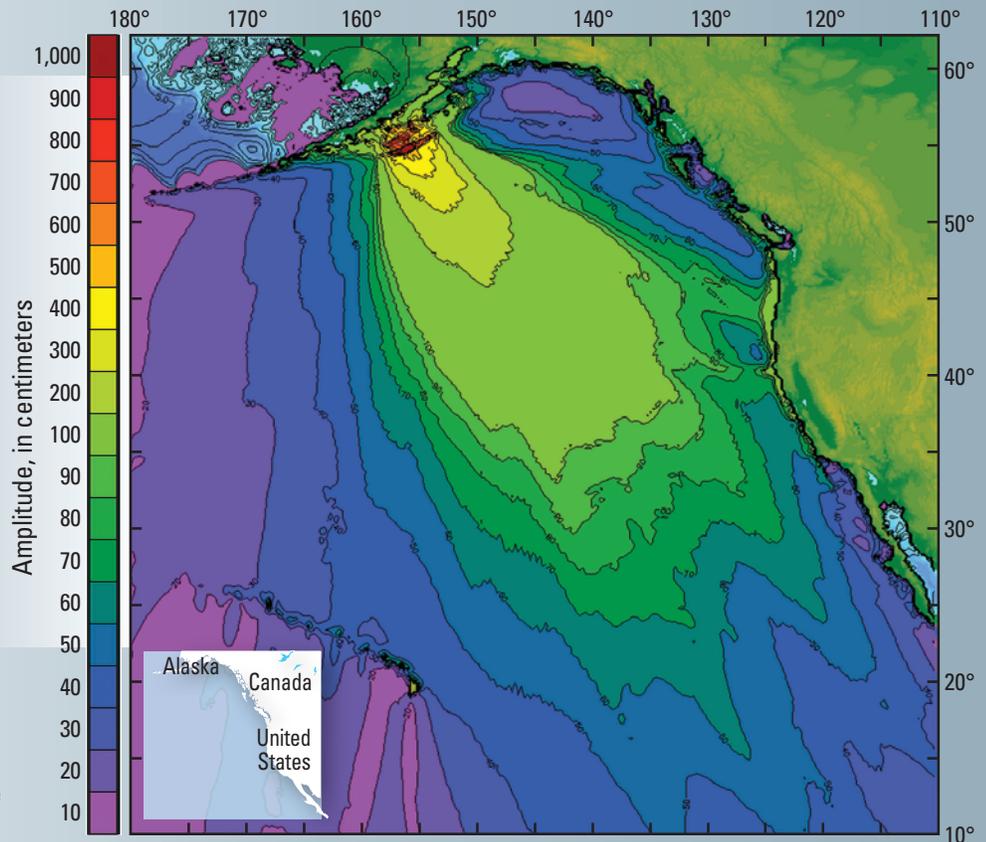


The SAFRR Tsunami Scenario—Improving Resilience for California

On March 11, 2011, the Tohoku earthquake and the resulting tsunami devastated Japan with a disaster of unfathomable proportions. Five thousand miles away, the waves from Tohoku caused \$50 to 100 million in damages in California. Although this pales in comparison to the loss of lives and property in Japan, the U.S. Government must ask whether California, and the national economy, will someday face worse consequences from other distant-source tsunamis. Unfortunately, the answer is “yes.”

Maximum wave amplitude (peak to trough height) of scenario tsunami throughout the northeast Pacific Ocean, as determined by the Method of Splitting Tsunami (MOST) model.



The U.S. Geological Survey’s Science Application for Risk Reduction (SAFRR) project and its partners created a tsunami scenario of a large hypothetical but plausible tsunami. The source of the tsunami is a moment magnitude 9.1 earthquake occurring offshore of the Alaska Peninsula. The team modeled the tsunami and its impact on the California coast. The scenario will serve as a long-lasting resource to teach preparedness and inform those who are responsible for making mitigation decisions before a future tsunami and those who will need to make rapid decisions during such events. Among these groups are emergency managers, business continuity planners, maritime managers, corporate real estate managers, land-use planners, and elected officials. Improved planning and more effective emergency response lowers losses during future tsunamis and benefits millions of people in California and elsewhere.

The SAFRR tsunami scenario included

- Spurring research related to Alaskan earthquake sources including studies of historic and prehistoric tsunamis in California;
- Developing advanced models of currents and inundation for the event;
- Evaluating the warnings and evacuations necessary to save lives with a special focus on vulnerable populations;
- Modeling tsunami damage to small craft and marinas;
- Estimating the physical damages, repair costs, and downtimes;
- Examining the economic impacts to the California economy with and without resilience strategies;
- Understanding the ecological, environmental, and societal impacts of coastal inundation;
- Engaging port, harbor, and U.S. Coast Guard decision makers;
- Creating enhanced communication products for education and decision-making before, during, and after a tsunami event; and
- Evaluating the scenario development process.

The State of California, through the California Geological Survey (CGS) and the California Office of Emergency Services (Cal OES), is using the SAFRR tsunami scenario to evaluate policies regarding tsunami impact. This broad array of work was carried out by the USGS in collaboration with the National Oceanic and Atmospheric Administration (NOAA), CGS, and Cal OES, as well as other academic, governmental, and private partners.

Due to the national economic importance of the Ports of Los Angeles and Long Beach, the source location was placed along the Alaska Peninsula because tsunamis generated there can have a significant impact on southern California. The source event is an earthquake similar in mechanism and magnitude to the 2011 Tohoku event, but set between Kodiak Island and the Shumagin Islands off the Pacific coast of the Alaska Peninsula. Similarities in geology and tectonic settings between Tohoku and this area suggest that the location is appropriate and the earthquake plausible.

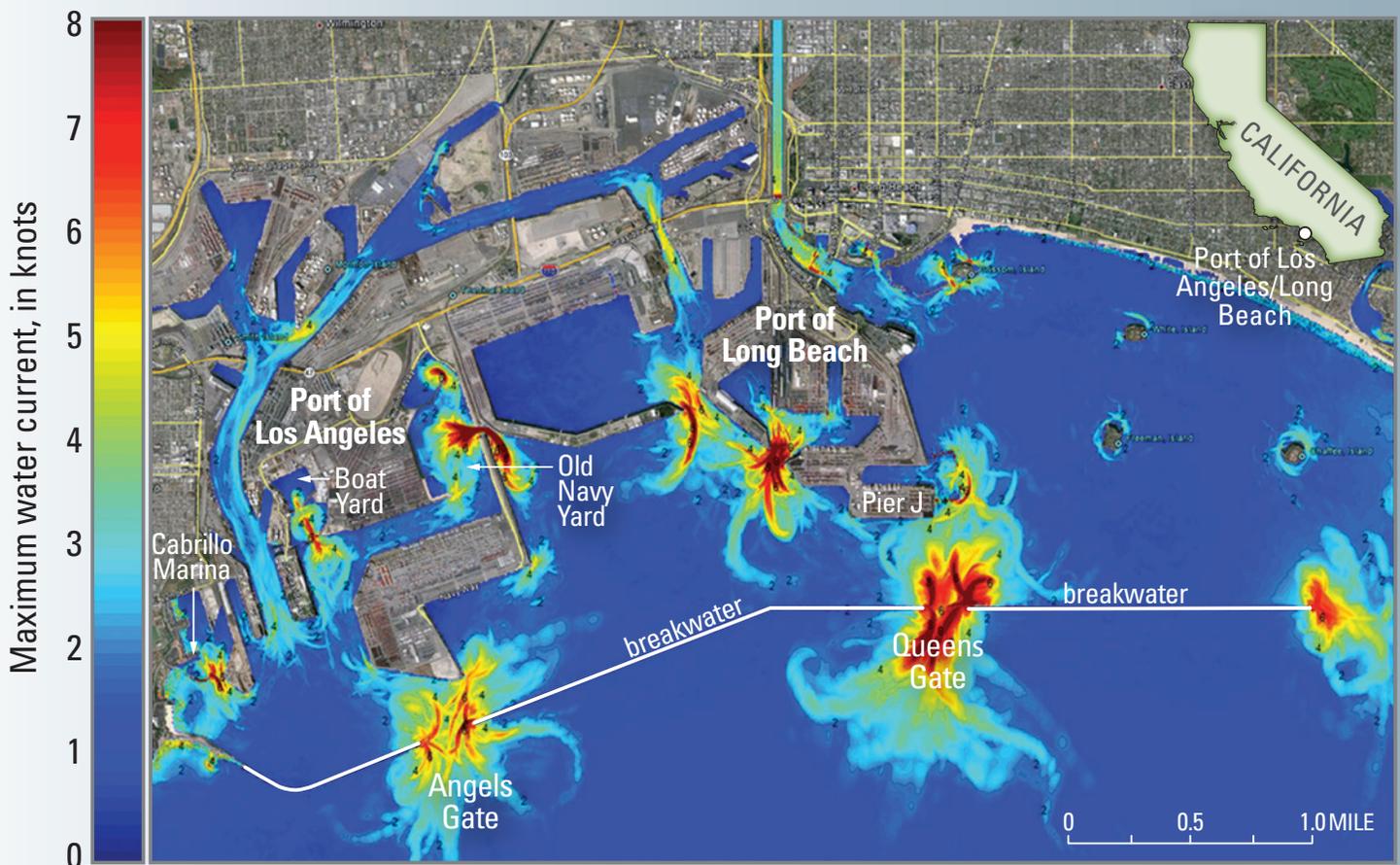
For purposes of making the scenario more tangible, we have simulated an earthquake that occurs at 11:57 a.m. PDT on Thursday March 27, 2014, which is the 50th anniversary of the 1964 Alaska

earthquake and tsunami. Travel times to California from the occurrence of the earthquake to the arrival of the first tsunami waves range from 4 hours in Crescent City to almost 6 hours in San Diego. Tsunami warnings and wave arrivals would occur during a workday afternoon.

On the day of the scenario, around a half million people would be present in the scenario's inundation area in California at residences and businesses, as well as public venues such as parks and beaches. Evacuation would likely be ordered for the State of California's previously designated maximum mapped tsunami inundation zone (based on a variety of possible tsunamis), evacuating an additional quarter million people from residences and businesses. Some island and peninsula communities would

face particular evacuation challenges because of limited egress options and short warning time. Evacuations would also be a challenge for dependent-care populations such as patients in hospitals and nursing homes and children in daycare facilities. Timing this scenario during summer months, when beach and coastal use is highest, would greatly increase the exposure of coastal populations, resulting in additional evacuation challenges.

Six teams were engaged to create models of the tsunami source and wave-propagation field. A coarse model of wave height was run for the entire Pacific basin, higher resolution models were run for coastal areas primarily in California, and current-velocity models were analyzed for selected ports and harbors. Where there was geographic overlap, the results



Maximum current speeds for the Port of Los Angeles (POLA) and the Port of Long Beach (POLB) generated during the SAFRR tsunami scenario. The ports are protected by a breakwater, but during the tsunami there would be dangerously fast currents around the port entrances in the wall, locally referred to as "Angels Gate" (at POLA) and "Queens Gate" (at POLB). In the POLA, powerful currents are also expected at Cabrillo Marina and the Boat Yard, where they could break apart floating docks, damage pilings, and pull small vessels from their mooring lines. The strongest currents would be expected in the Old Navy Yard; however, there are no exposed floating assets in that immediate area. In the POLB, jet-like currents would be likely at the entrance to the main cargo container area (Pier J) and may be sufficient to damage, and possibly break, mooring lines.



Areas that would be inundated (in red) during the SAFRR tsunami scenario. Top, in Oakland and Alameda, in the eastern San Francisco Bay area, large parts of the Oakland Airport would be flooded. Bottom, in Newport Beach, Orange County, there would be complete or partial flooding of all islands and near overtopping of the Balboa Peninsula neighborhood, possibly creating evacuation challenges.

are remarkably similar even though the modeling methods differ. Tsunamis increase in height as they approach the shore. In southern California, the peak tsunami heights would range from 5 to 10 feet near shore. In central California, from Lompoc through Marin County, they would range from 8 to 24 feet. And in northern California, the peak tsunami heights would range from 9 to 23 feet. High tide could increase these values by about 3 feet above normal tide conditions. The models can be used to draw inundation lines that delimit the area of dry land that floods during

a tsunami. Those inundation lines were adjusted by examining fine-scale structures such as steep beaches and levees that may not be well represented in the gridded bathymetric and topographic data used in the numerical calculations.

We determined how often tsunami waves similar to those in the SAFRR tsunami scenario would impact different spots along the California coast. Using an aggregate of sources from around the Pacific Ocean, tsunamis with the same or larger offshore amplitude as those in the scenario would occur, on average, on the order of hundreds of years.

In the SAFRR tsunami scenario model, the initial waves at each location are among the largest. However, the first wave is the largest one in only a few locations such as Monterey Bay and Morro Bay. In most cases the largest waves arrive several hours—sometimes more than 7 hours—after the initial one.

Current velocities were modeled in detail around the Ports of Los Angeles and Long Beach, San Diego, and Ventura Harbor. Where the tsunami is forced through channels, localized high-current velocities can cause jets and whirlpools that can damage boats and structures and

make navigation dangerous. In Ventura Harbor, maximum currents would exceed 14 knots and there would be widespread speeds of 8 knots, which is fast enough to cause significant damage. In contrast, the Ports of Los Angeles, Long Beach, and San Diego would experience widespread currents of only a few knots and the currents would reach 6 to 8 knots in just a few locations. In those places, the currents would be sufficient to damage structures and potentially break mooring lines.

In California's coastal marinas one third of the boats could be damaged or sunk and over half of the docks could be damaged or destroyed. Fires ignited by electrical problems would likely start at many sites where fuel and petrochemicals are stored in ports and marinas. Tsunami surges and bores could travel several miles inland up coastal rivers. Potential sediment transport and environmental contamination would increase the recovery costs significantly. Removal of debris and recovery of inundated and damaged areas would take days, months, or years depending on the severity of impacts and the available resources for recovery.

Some commercial fishing vessels may be directly damaged by the tsunami, while other boats would be unable to operate because of damage to harbors and fish-processing plants. The fisheries themselves, especially nearshore invertebrate fisheries, would also be affected. Other potential ecological damage includes erosion of beach sand and contamination of marshes, features that, if intact, help protect communities from the tsunami.

The Ports of Los Angeles and Long Beach would be shut down for a minimum of two days because of strong currents. Inundation of dry land in the Ports of Los Angeles and Long Beach could result in approximately \$100 million in damages to cargo and additional downtime at some terminals. Losses from the disruption of port trade could total more than \$1.2 billion, whereas associated business-interruption losses in the California economy could be more than triple that value. Other estimated costs include \$2.6 billion in property damage, \$700 million in marina and small craft damage, and \$85 million for highway and railroad repairs.

The estimated repair and replacement costs in California marinas, coastal properties, and the Ports of Los Angeles and Long Beach amount to \$3.4

Potential economic losses due to physical damage and business interruption in the SAFRR Tsunami Scenario.

Assets	Repair cost (in millions ¹)	Business interruption strategies (in millions ¹)	
		Without resilience	With resilience
Ports of Los Angeles and Long Beach	\$100	\$4,300	\$200–\$900
Fishing in Port of Los Angeles		\$2	\$0.3
Marinas and small craft	\$700	\$30	
Property	\$2,600	\$1,700	\$300
Roads and bridges	\$80		
Railroads	\$2		
Agriculture	\$4		
Total (rounded)	\$3,500	\$6,000	\$500–\$1,200

¹Figures are in 2010 U.S. Dollars. For 2013, add 6%

billion. Business interruption losses from these damages and port shutdowns total \$6 billion, assuming no resilience in the California economy. The adoption of resilience strategies (for example, using existing inventories and working extra shifts) could reduce the losses by 80 to 90 percent. Without resilience strategies, the costs and the economic impacts could be almost \$10 billion in property damage and business-interruption losses.

This tsunami scenario provides the basis for improving preparedness, mitigation, and continuity planning, which can reduce damage and economic impacts and enhance recovery efforts. Positive outcomes have already resulted from the SAFRR tsunami scenario. For instance, emergency managers have updated evacuation plans in the few areas where the SAFRR scenario inundation exceeds the State's maximum inundation zone. The State has also worked with the National Oceanic and Atmospheric Administration West Coast and Alaska Tsunami Warning Center to modify future message protocols, moving the location of a preset breakpoint between alert zones that would have impeded effective evacuations in this scenario. Although our specific results pertain to California, the approach and lessons learned from our scenario can be applied to other regions. The occurrence of future tsunamis along the West Coast will likely differ in many details; however, the SAFRR tsunami scenario provides a useful tool for planning.

Stephanie L. Ross, Lucile M. Jones, Kevin Miller, Keith A. Porter, Anne Wein, Rick I. Wilson, Bohyun Bahng, Aggeliki Barberopoulou, Jose C. Borrero, Deborah M. Brosnan, John T. Bwarie, Eric L. Geist, Laurie A. Johnson, Stephen H. Kirby, William R. Knight, Kate Long, Patrick Lynett, Carl E. Mortensen, Dmitry J. Nicolsky, Suzanne C. Perry, Geoffrey S. Plumlee, Charles R. Real, Kenneth Ryan, Elena Suleimani, Hong Kie Thio, Vasily V. Titov, Paul M. Whitmore, and Nathan J. Wood

Edited by *Claire M. Landowski*
Graphics and layout by *Jeanne S. DiLeo*

For more information contact:

U.S. Geological Survey
Science Application for Risk Reduction (SAFRR)
http://www.usgs.gov/natural_hazards/safrr/
safrr@usgs.gov

The SAFRR tsunami scenario USGS and CGS report
<http://pubs.usgs.gov/of/2013/1170/>

CGS SAFRR tsunami scenario page:
http://www.conservation.ca.gov/cgs/geologic_hazards/Tsunami/Pages/SAFRR.aspx

California tsunami information:
<http://www.calema.ca.gov/PlanningandPreparedness/Pages/Earthquakes-and-Tsunamis.aspx>

To access California inundation maps for your area:
<http://www.tsunami.ca.gov>

NOAA tsunami information:
<http://www.tsunami.noaa.gov/>

This Fact Sheet and any updates to it are available online at <http://pubs.usgs.gov/fs/2013/3081>