California's Tsunami Risk

A Call for Action

Recent tsunamis and research findings cast a new perspective on the vulnerability of California's coastal communities to tsunamis. This document presents a timely overview of our risk and lists specific actions any one of which can be undertaken to significantly reduce loss of life, and lessen the social and economic disruption that could result from such an event.

“The ocean withdraws, comes barreling in 25 feet high in the fourth large deadly wave and goes inland two miles. At this time, you have tanks exploding, you have 300 buildings and businesses destroyed. You have a third of the community homeless…”

Account of the 1964 Crescent City, California tsunami from *The Raging Sea* by Dennis Powers

Cover: A portion of downtown Crescent City, California that was destroyed by a tsunami triggered by the M9.2 Great Alaska Earthquake that occurred on Good Friday, March 27, 1964 *(Source: U.S. Geological Survey).*

CALIFORNIA'S TSUNAMI RISK
A Call for Action

A Report from the

CALIFORNIA TSUNAMI POLICY WORKING GROUP

2014

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Executive Summary

This report summarizes current views on California's tsunami hazard and risk in the wake of recent devastating tsunami disasters around the world, and presents a series of 47 recommendations to reduce tsunami risk along California's coast. These recommendations are the result of deliberations over the past three years by the California Tsunami Policy Working Group. The ad hoc working group consists of volunteer experts in earth science, flood hazard, structural and coastal engineering, local and regional planning, and natural hazard policy who have collectively considered the latest science on the tsunami threat and principal issues, policy gaps, and roadblocks inhibiting effective tsunami hazard mitigation to develop practical, workable solutions.

Since the disastrous 2004 Indian Ocean tsunami, there have been a sequence of devastating tsunamis around the world and new research over the past decade has found that California's potential tsunami risk is far greater than previously thought and giving rise to a more urgent need to lessen the impact of these rare, but credible, threats. More than a quarter of a million Californians, over 15,000 businesses, and hundreds of billions of dollars in buildings, infrastructure, port, maritime, agriculture and other assets in the state are at risk of tsunami inundation every day. The frequency of damaging tsunami waves striking the California coast from major earthquakes around the Pacific Rim is on the order of a hundred to a few hundred years. This is comparable to the probability of great floods impacting California's Central Valley, or a great earthquake occurring along the southernmost segment of the active San Andreas Fault.

This report is presented in two parts: Part A provides an up-to-date perspective on California's tsunami hazard, exposure, risks and status of mitigation. Part B presents 47 recommended actions that if undertaken could significantly reduce the impact of future tsunamis on coastal communities. These actions are organized around a framework of three goals to: 1) Build a solid foundation from mitigation; 2) Practice risk-based land-use and construction; and 3) Enhance emergency management. The full list of recommendations is provided below; however, key among them are:

- Support continuation of the National Tsunami Hazard Mitigation Program, TsunamiReady® and affiliated state and local programs, and recruit and assist all coastal communities, ports and harbors to become TsunamiReady®. Unless the federal Tsunami Warning and Education Act is reauthorized, the foundation of the nation's and the State's tsunami policy framework will be significantly diminished and the future of the TsunamiReady® and State leadership for local tsunami hazard assessment, mitigation and preparedness will be at significant risk;
- Establish State-delineated tsunami hazard zones appropriate for application through the Seismic Hazard Mapping Act, with guidance for tsunami resilient land use planning and building codes;
- Promote a suite of improvements to tsunami hazard warning messaging and communication;
- Develop products to improve maritime and harbor hazard assessments, preparedness and planning.

Tsunamis have occurred in California's past, and our scientific understanding of the Pacific Rim's earthquake potential, including sources from the very nearby Cascadia Subduction Zone on the U.S. west coast, assures us that much larger tsunamis that are much more capable of causing serious damage to today's heavily-developed coastline, will occur in the future—although it is uncertain when. Nonetheless, the time to prepare is now.

47 Recommended Actions

Comprehensively Assess Tsunami Hazard Likelihood and Severity (pages 20 – 22)

- ❖ Support development and evaluation of advanced tsunami hazard assessment models. (p. 21)
- ❖ Require that tsunami hazard models used to estimate tsunami and seiche inundation hazard for public policy purposes are: peer-reviewed and tested, published in professional peer-reviewed literature, or are otherwise professionally recognized as "standard-of-practice." (p. 21)
- ❖ Require all computer software used to model inundation and develop public policy guidance products to be open and fully transparent to permit full and effective testing and evaluation. (p.21)
- ❖ Expand the test program administered by the National Tsunami Hazard Mitigation Program to include an evaluation of all models used to estimate the likelihood and severity of tsunami inundation. (p.21)
- ❖ Analyze the tsunami hazards within ports, harbors and marinas focusing on high-current velocity, turbulence, eddies, and other hazardous conditions to identify high hazard areas. (p. 22)
- ❖ Determine, in a consistent manner, the seaward extent of hazardous wave action along California's coast. (p. 22)

Improve Our Understanding of Tsunami Risk and Ways to Reduce It (pages 22 – 23)

- ❖ Research the hydrodynamic effects of existing development and proposed locations of future development on flow velocity and consequent structural loading during tsunami inundation, as well as ways to account for these effects in the engineering design process. (p. 23)
- ❖ Identify ways to provide incentives for cities, counties, and special districts to become TsunamiReady®. (p. 23)

Establish a Framework to More Effectively Communicate Tsunami Warnings (page 23)

- ❖ Expedite efforts already underway to establish agreements between government agencies that issue warnings and cellular network providers. (p. 23)

Capitalize on National Efforts to Reduce Tsunami Risk (pages 23 – 24)

- ❖ Support reauthorization of the federal Tsunami Warning and Education Act and continue to assist coastal communities in becoming TsunamiReady®. (p. 23)

Condition Development in Areas Exposed to Tsunami Hazards (pages 24 – 26)

- ❖ Establish State-designated tsunami hazard zones appropriate for application to land-use planning and tsunami resilient building codes that are currently under development. (p. 24)
- ❖ Form an advisory committee to guide development of mapping criteria to be used in delineating State-designated tsunami hazard zones and the guidelines for local agencies to use in implementing the zones. (p. 25)
- ❖ Establish special State-designated tsunami hazard zones that would trigger risk-based design and construction of new critical facilities, essential services facilities, and infrastructure. (p. 25)
- ❖ Modify the existing framework of the Seismic Hazards Mapping Act (Public Resources Code, Chapter 7.8, Sec. 2690 et seq.) to include site-specific tsunami hazard investigations consistent with those to be specified in tsunami building code provisions. (p. 26)

- Amend California's natural hazards disclosure law (California Civil Code Sec. 1103 et seq.) to require the buyer of real property to be notified if the property is located in a State-designated tsunami hazard zone. (p. 26)

Implement Tsunami Resilient Building Codes (pages 26 – 28)

- Amend existing design and construction codes to include the risk-based assessment of anticipated tsunami forces and their impacts on proposed structures and project sites, and develop provisions that meet pre-defined performance standards. (p. 27)
- Increase the ISO Building Code Effectiveness Grading Schedule (BCEGS) rating based upon adoption of tsunami resilient provisions into community building codes. (p. 27)
- Support continuation of the California Geological Survey's work with the ASCE Subcommittee on Tsunami Loads and Effects to develop prototype probabilistic inundation maps from local and distant tsunami sources to assist in the development of tsunami building code provisions. (p. 27)
- Require State-designated tsunami hazard zones under the Seismic Hazards Mapping Act (Public Resources Code, Chapter 7.8, Sec. 2690 et seq.) to be compatible with those used to trigger tsunami building code provisions. (p. 27)
- Include the broad topic of tsunami hazard in college curricula, licensing, and continuing education in coastal engineering, structural engineering and civil engineering. (p. 28)
- Encourage inclusion of tsunami hazard and engineering in the certification program for coastal engineering provided by the Academy of Coastal, Ocean, Port & Navigation Engineers (ACOPNE). (p. 28)
- Establish guidelines for the formal certification of coastal engineers as a specialty within civil engineering. (p. 28)
- Support development of additional tsunami hazard products necessary to implement tsunami code provisions. (p. 28)

Consider Tsunami Hazards in Land-Use Decisions (pages 28 – 29)

- Require that any tsunami resilient building code provisions included in the California Building Code be applied throughout the full geographic extent of State-designated tsunami hazard zones. (p. 29)
- Amend state general plan laws and programs to require consistent recognition and application of State-designated tsunami hazard zones within the hazard identification and risk assessments of the State Hazard Mitigation Plan, Local Hazard Mitigation Plans, Local Coastal Programs, and local general plans. (p. 29)
- Amend California law to include financial incentives that encourage coastal communities to adopt consistent land use policy within State-designated tsunami hazard zones, and integrating mitigation policies, strategies and actions of their Local Coastal Program land-use plans, local general plans, and Local Hazard Mitigation Plans. (p. 29)

Enhance Multi-Jurisdictional Planning for Tsunami Hazard (pages 29 – 30)

- Support the development of comprehensive multi-jurisdictional multi-hazard mitigation plans that work to resolve inconsistencies among adjacent jurisdictions. (p. 30)
- Incorporate tsunami hazards into regional land-use planning and strategies to mitigate climate impacts, such as increasingly intense coastal storms, coastal flooding, and sea level rise. (p. 30)

Increase the Effectiveness of Tsunami Hazard Warnings (pages 30 – 32)

- ❖ Continue support for the development and full implementation of the FEMA-FCC-wireless carrier partnership and application of regional broadband public safety networks in California. (p. 31)
- ❖ Develop standardized mobile phone applications that allow receipt of tsunami evacuation warnings from local emergency services agencies. (p. 31)
- ❖ Develop guidance for local response agencies to determine when to issue the "all clear" following tsunami alerts. (p. 32)
- ❖ Continue Live Code (end-to-end) communications tests of the Emergency Alert System to ensure that the tsunami warning can be effectively and properly delivered during an actual event. (p. 32)

Address Regional Preparedness, Response, and Recovery Issues (pages 32 – 34)

- ❖ Continue to support the State and local partnership for coordinated and consistent implementation of the TsunamiReady® program in coastal communities. (p. 33)
- ❖ Establish a dedicated web service to share tsunami preparedness and response activities among coastal communities. (p. 33)
- ❖ Help regional associations of governments to collaborate with California's coastal cities and counties in inter-jurisdictional preparedness, response, and recovery planning. (p. 33)
- ❖ Conduct a comprehensive and coordinated scenario-based vulnerability assessment of critical facilities along California's coast based on probabilistic estimates of tsunami inundation to help facilitate regional, multi-jurisdictional tsunami preparedness planning. (p. 33)
- ❖ Develop guidance to assist cities, counties, and special districts (including school, water, port and harbor districts) to prepare pre-disaster operational recovery plans for tsunami hazards. (p. 33)
- ❖ Incorporate more information on tsunami education and preparedness into the Great California Shakeout™ program's goals and objectives, the program website, education material, and preparedness activities. (p. 34)
- ❖ Expand California's "Tsunami Preparedness Week" to "Tsunami Preparedness Month." (p. 34)
- ❖ Develop guidance for private businesses, such as coastal hotels and resorts, to plan, prepare, and implement tsunami awareness measures. (p. 34)
- ❖ Encourage property owners and renters located within State-designated tsunami hazard zones to obtain coverage from the National Flood Insurance Program. (p. 34)

Prepare the Maritime Sector for Tsunami Hazards (pages 35 – 36)

- ❖ Form an advisory committee to prepare and distribute consistent, statewide procedural guidelines for maritime tsunami response and recovery. (p. 35)
- ❖ Develop State guidelines for harbor authorities to use in preparing tsunami preparedness, response, and recovery plans for their facilities. (p. 35)
- ❖ Develop guidelines for harbor authorities to establish a State-approved boater safety training program with a tsunami hazard component and procedures for vessel evacuation. (p. 35)
- ❖ Add a tsunami hazard component to ship pilot licensing programs. (p. 36)
- ❖ Streamline federal, state, and local permitting for post-disaster disposal of dredge spoils and promote pre-designation of disposal sites to help expedite the process in the event of a disaster. (p. 36)

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PART A – THE TSUNAMI THREAT

Introduction

There are few natural phenomena as devastating as a tsunami. Similar to tornadoes and wildfires, people, buildings, cars, and boats in the hazard path rarely come out unscathed. Although our state resides along the Pacific Rim of Fire, which is the source of many of the world's largest earthquakes and accompanying devastating tsunamis, only some California faults are capable of generating a large tsunami. We are, however, also quite vulnerable to tsunamis generated by distant sources in Alaska, Chile, Japan, and all around the Pacific Rim as witnessed on March 11, 2011 when the tsunami caused by a magnitude 9 earthquake in Japan struck Crescent City, Santa Cruz (see Figure 1) and elsewhere along the California coast.

More than a quarter of a million Californians, over 15,000 businesses, and hundreds of billions of dollars in buildings, infrastructure, port, maritime and other assets in the State are at risk every day from tsunamis.[1] The tragedy of the 2004 Indian Ocean tsunami raised national and international awareness and funding for tsunami hazard mitigation and preparedness. Since then, much has been done to improve California's tsunami warning system and to help coastal communities with emergency preparedness and public education, in particular.

Figure 1. Santa Cruz marina as it is struck by the tsunami originating in Japan following a magnitude 9 earthquake on March 11, 2011. *(Source:http://www.latitude38.com/lectronic/lectronicday.lasso?date=2011-12-30#.UmRZ4BDi7pc)*

However, the State's policy and program support framework for managing tsunami risk is fragmented and relatively weak compared with other hazards, such as river flooding and earthquake shaking. This is in part due to our relatively recent understanding and better characterization of the risk and not a criticism of the State's tsunami program. Major policy changes and additional public investments are needed at the State and local levels to ensure that California residents, businesses and coastal communities are better able to manage tsunami hazards and are also adequately prepared to respond to and recover from a major tsunami disaster. This report, prepared by the California Tsunami Policy Working Group outlines what needs to be done to lower the risk and protect public health and safety.

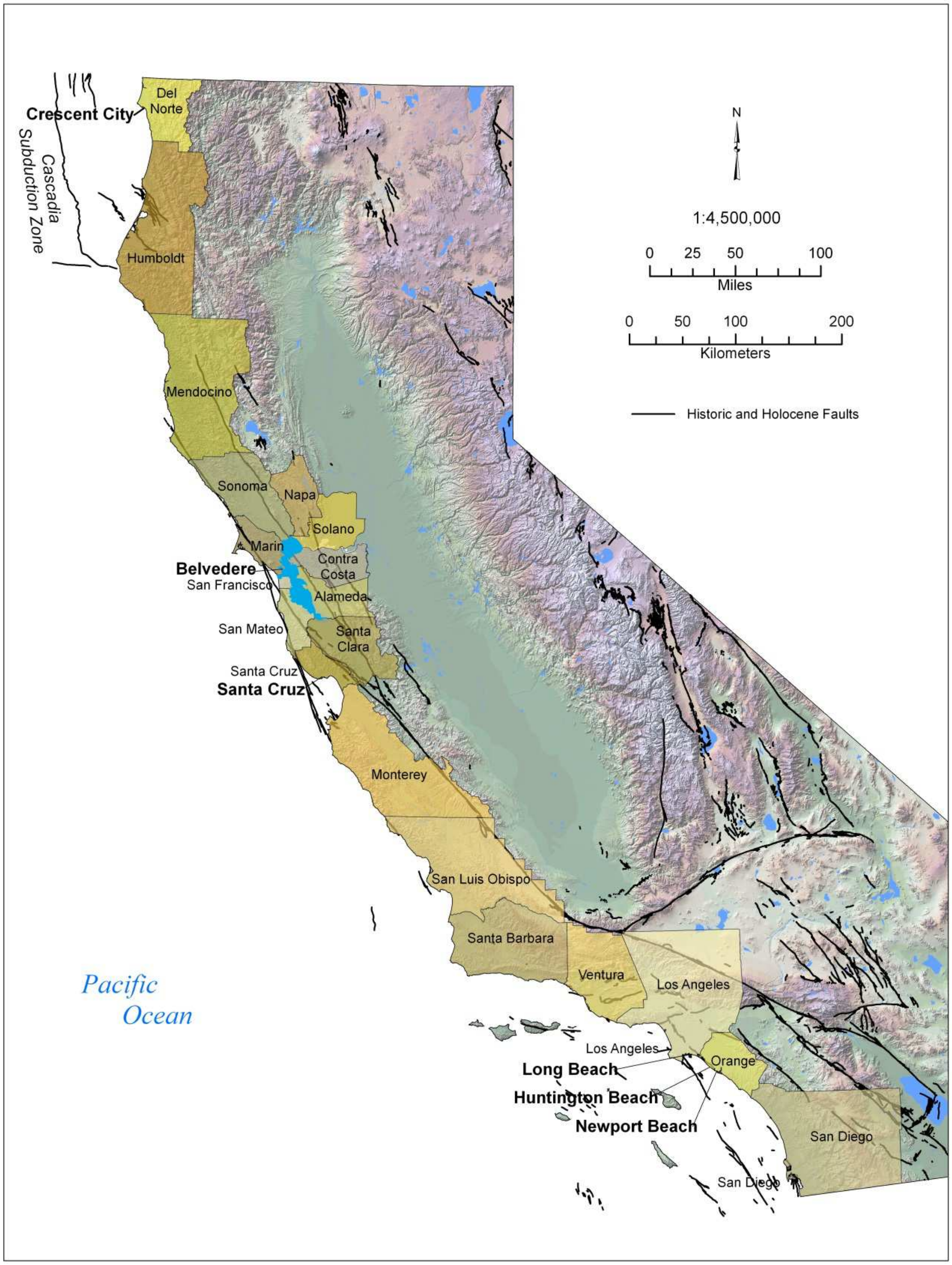


Figure 2. California's coastal counties that are subject to tsunami hazards. Locations of the six cities which have tsunami inundation modeling results presented in Figure 3 are shown in bold on the figure. Active faults (movement in the past 11,000 years) are shown in black. Many of those offshore faults have evidence of vertical movement with a potential to generate tsunamis. The location of the Cascadia Subduction Zone is also identified.

Who and What is at Risk of Tsunami Inundation in California?

Two-thirds of the more than 1,100 miles (1,770 kilometers) of California coast are naturally protected from tsunamis by cliffs and steeply-sloped shores.[2] However, the low-lying coastal areas are at greatest risk of tsunami inundation and these also happen to be some of the most densely developed and populated parts of our state (see Figure 2).

People and Places at Risk

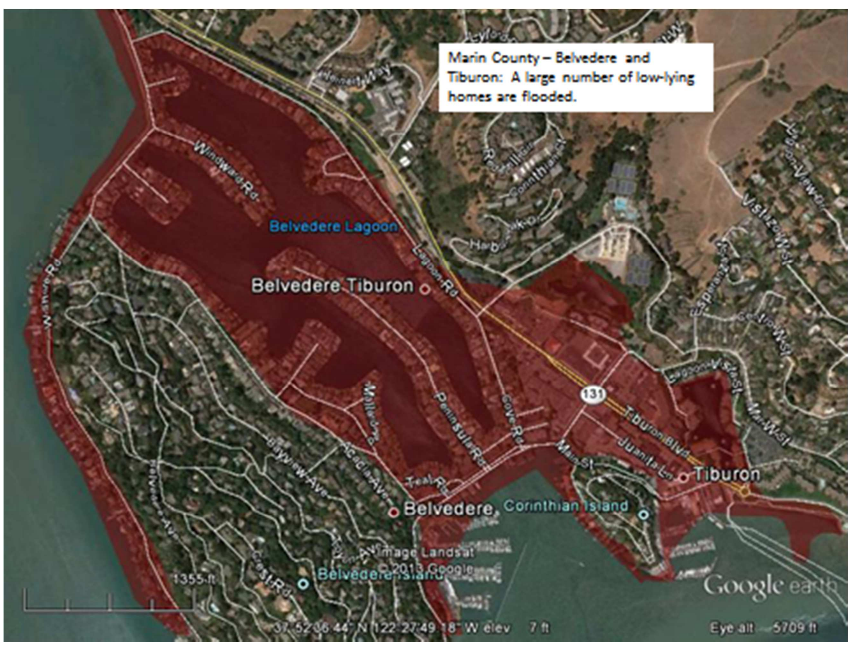
Within California's 20 coastal counties, there are 94 incorporated cities and 83 unincorporated communities at risk of tsunami inundation.[3] 267,347 people (or 117,380 households) permanently reside in potential tsunami inundation areas identified by the State of California.[4] While this is just roughly one percent of the 20-county resident population, vacation households and summertime populations can easily swell this figure to more than three million on any given day as other Californians and visitors flock to coastal amusement parks, marinas, city and county beaches, and state and national parks.[5]

The cities of San Francisco, Alameda, Los Angeles, Long Beach, Huntington Beach, Newport Beach, and San Diego all have more than 10,000 residents living in potential tsunami inundation areas.[6] The City of Alameda has the highest number (39,515 residents), which is over 50 percent of the city's total population.[7] Other smaller communities with high percentages of residents in potential tsunami-inundation areas include Crescent City, Belvedere, Emeryville, Seal Beach, Del Mar, Coronado, and Imperial Beach.[8] Also, 12 percent of the State's at-risk population resides in unincorporated communities.[9] All these communities could face tremendous challenges evacuating residents ahead of a tsunami's arrival, especially island and peninsula communities with limited exit options. These communities could also face significant challenges in rebuilding following a damaging tsunami.

Figure 3 shows the anticipated flooding in parts of Crescent City, Belvedere, Santa Cruz, Long Beach, Huntington Beach, and Newport Beach, from a potential tsunami caused by a magnitude 9.1 earthquake off the southern coast of Alaska.[10] While such a tsunami could cause damage along the entire California coast, it is definitely not the worst case scenario. The anticipated flooding from a range of large and credible tsunami sources, both near-shore and further afield, is generally greater along most of the California coastline than what was calculated for this particular scenario.

It is also important to note that community vulnerability to tsunamis can vary considerably from place to place. Sixteen percent of at-risk residents are more than 65 years in age, 13 percent identify themselves as Hispanic or Latino, 14 percent identify themselves as Asian, and 51 percent of the households are renter-occupied.[11] Several at-risk areas also have high numbers of residents in institutionalized and non-institutionalized group quarters, such as correctional facilities and military housing.

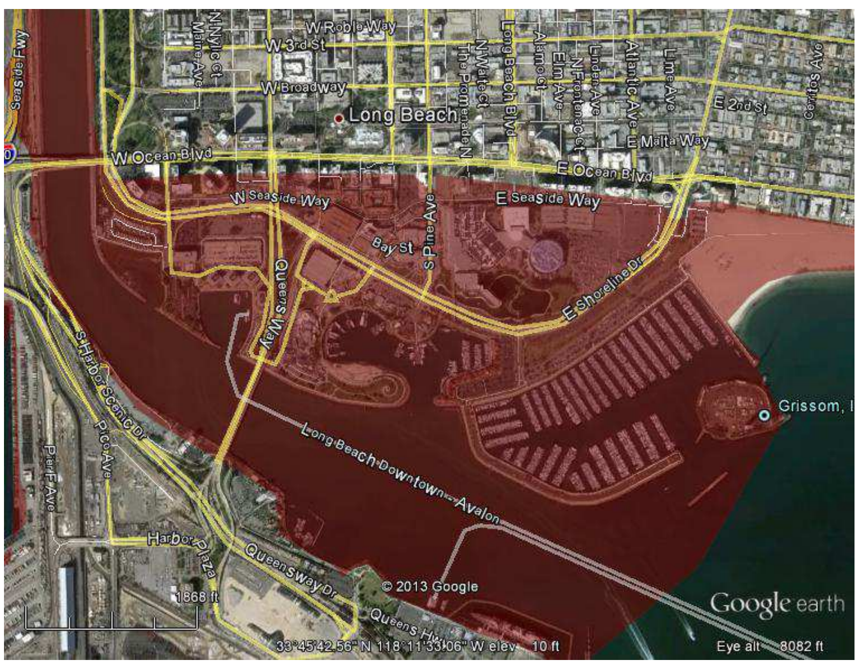
a) Crescent City



b) Belvedere

Figure 3. Anticipated flooding in parts of a) Crescent City, b) Belvedere, c) Santa Cruz, d) Long Beach, e) Huntington Beach, and f) Newport Beach, from a potential tsunami caused by a magnitude 9.1 earthquake centered off the coast of Alaska*. (Source: Ross and Jones, SAFRR Scenario, 2013)*

c) Santa Cruz



d) Long Beach

Figure 3 continued. Anticipated flooding in parts of c) Santa Cruz, and d) Long Beach, from a potential tsunami caused by a magnitude 9.1 earthquake centered off the coast of Alaska. *(Source: Ross and Jones, SAFRR Scenario, 2013)*

e) Huntington Beach

f) Newport Beach

Figure 3 continued. Anticipated flooding in parts of e) Huntington Beach, and f) Newport Beach, from a potential tsunami caused by a magnitude 9.1 earthquake centered off the coast of Alaska. *(Source: Ross and Jones, SAFRR Scenario, 2013)*

There are also many dependent-population facilities, such as schools and child daycare centers, located in at-risk areas. The age, race and ethnicity, and household status of residents in tsunami-prone areas can present a range of challenges for tsunami education, preparedness and evacuation planning. It can also present a range of challenges in sheltering impacted residents and restoring communities following a major tsunami disaster.

Buildings, Businesses, and Infrastructure at Risk

Over 265 million square feet of commercial and residential building space valued at $35.33 billion, along with $23.22 billion in contents, are located in tsunami vulnerable locations along the California coast.[12] Communities with the highest percentages of developed land exposed to tsunami inundation include Eureka, Crescent City, and unincorporated areas of Humboldt County in the far North; Larkspur, Belvedere, Sausalito, Emeryville, and Alameda in the San Francisco Bay Area; Morro Bay and Avalon on the central coast; and Coronado and Del Mar in southern California) (See Figure 4). [13] In just two cities, Oakland and Los Angeles, over 11,600 acres (18 square miles or 47 square kilometers) of developed land are exposed to tsunami inundation.[14] All these communities could face the greatest levels of damage, and thus the greatest challenges in recovery following a major tsunami.

Potential tsunami inundation areas are also some of the most economically viable parts of the state. 15,335 California businesses are located in tsunami vulnerable coastal areas.[15] They generate almost $30 billion in annual sales and employ 168,565 people (two percent of the 20-county labor force).[16]

Communities with the highest numbers of employees working in potential tsunami inundation areas are the cities of Oakland (22,176), Long Beach (16,506), Alameda (15,441), and Los Angeles (9,581), related in large part to port activities within each city.[17] Other communities with high percentages of their local workforce in potential tsunami inundation areas include Crescent City, Belvedere and Del Mar.

With Los Angeles, Long Beach, and Oakland at the helm, California has some of the largest and busiest ports in the United States. The Ports of Los Angeles and Long Beach combined are the country's top container port.[18] In a major tsunami, all of California's ports, large and small, could simultaneously experience damage and would be at risk of losing business to other ports outside California if operations are down for an extended period of time. This could have significant regional and statewide economic impacts. The cost of just a 2-day shutdown at the Ports of Los Angeles and Long Beach, as well as facility downtime and cargo losses associated with a major tsunami, could amount to $4.3 billion in economic losses for southern California and the rest of California.[19]

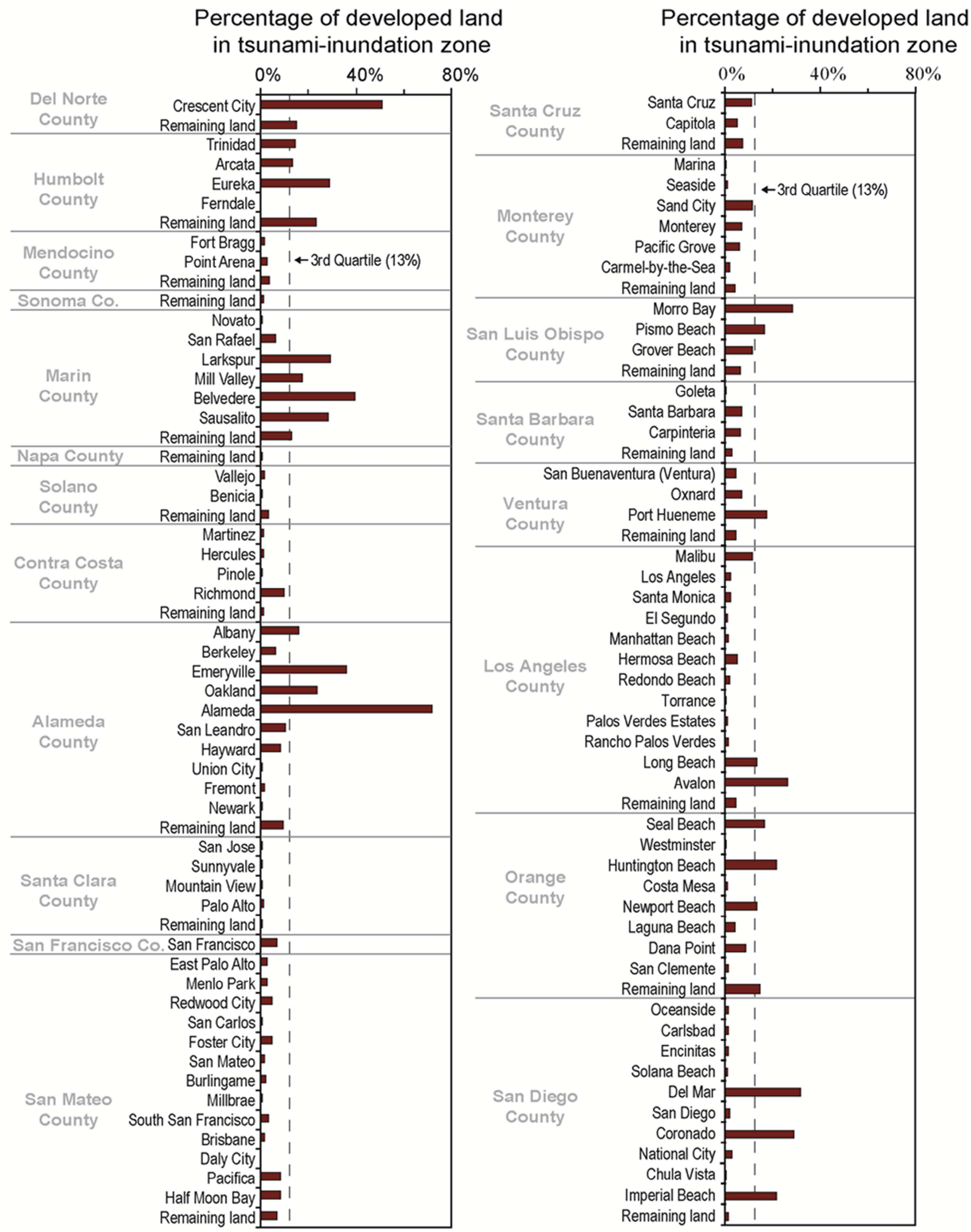


Figure 4. Percentage of developed land in the State of California Tsunami Inundation Zone *(Source: Wood and Others, 2013).*

The California coast and many of the State's major port complexes are also home to petrochemical facilities, oil tank farms, fuel storage, and other hazardous materials storage facilities that are vulnerable to damage and sources for contamination and fires in tsunamis.[20] If such a fire were to occur, it could spread over water and possibly destroy other facilities as well.[21]

There are also hundreds of marinas and small craft harbors along the State's coast and bays that are tsunami vulnerable. The large waves and currents associated with a major tsunami could severely damage or sink nearly all the floating docks and boats in their path. The resulting debris combined with sedimentation could close navigation channels, taking years to dredge and restore. Crescent City completed $33 million in harbor repairs in November 2013, over 2 ½ years after sustaining damages from the March 11, 2011 Japanese tsunami.[22]

Fishing, recreation and tourism, and other related industries can be devastated by prolonged harbor and marina closures and the ecological damage caused by a major tsunami. Statewide, the fishing industry is vulnerable to damage to boats and infrastructure, such as docks and processing plants, caused by tsunami waves, currents, debris and other factors.[23] Damage to offshore fishing beds and aquaculture, fishing fleets and harbors, and onshore fishing facilities, could devastate California's fishing industry and surrounding communities and take years to recover.[24]

Next to shipping related enterprises, tourism is the second largest economic sector at risk from tsunamis in California.[25] Tsunamis can directly impact the many coastal assets that attract millions of visitors per year and also cause significant environmental contamination and devastation both on- and off-shore.[26] This could take many years to clean-up and restore and result in prolonged or even permanent closures of state and national parks, city and county beaches, and other tourist attractions. Fragile ecosystems, such as wetlands, eroding beaches, waterways, and critical habitat or breeding grounds might never be restored.[27] There are also thousands of coastal hotels, restaurants, and other food and accommodation services and businesses that would incur both direct and indirect losses from tsunamis and protracted recovery efforts.

Substantial portions of California's coastal agriculture are also at risk of tsunami inundation. A tsunami could destroy crops, pastureland, livestock, farm equipment and buildings.[28] Furthermore, salinization and contamination of water and soil, soil scour, and debris, all can present long-term recovery and restoration issues for affected farms.[29] The 2004 Indian Ocean and 2011 Tohoku, Japan, tsunamis caused tremendous agricultural losses and it has taken years to clean-up and bring agricultural lands in affected countries back into production. Much of California's vulnerable coastal agricultural land is located in rural areas where smaller coastal farms and enterprises could be disproportionately affected and recovery slowed by a lack of resources.[30]

Low-elevation roads, railways and bridges along California's coast and bays are also vulnerable to tsunami inundation. Tsunamis can scour away roads and rail beds, as well as bridges and embankments, and tsunami-borne debris can create additional damage.[31] Many of California's coastal highways are strategic to the State and nation's defense and also critical for emergency access and moving goods and supplies. Tsunami-damaged water supplies can also hinder fire-fighting capabilities. Major repairs and prolonged outages of roadways, railways, and other critical infrastructure for many months, or even longer, could impede regional and statewide recovery and have economic consequences as well.[32]

How Great is the Risk?

In California's history, most of the more well-known earthquakes, like the Great 1906 San Francisco, 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes, did not generate a tsunami. This is because some of the state's most active faults are located primarily on land. For the offshore portions of our major faults, many tend to rupture laterally. This means that with a predominantly horizontal strike-slip movement most of California's faults do not thrust upward and displace large volumes of ocean water when they rupture. This is true for major faults located offshore like the San Andreas and San Gregorio faults in northern California, and the Newport-Inglewood and Rose Canyon fault systems in southern California.

Time-Critical Near-Shore Tsunami Sources

California does, however, have some very dangerous near-shore faults and other hazards capable of generating a tsunami with little to no advance warning. The risks are far greater from near-shore sources because there is far less time to evacuate and take other preventive measures when they happen. As was tragically witnessed in the Tohoku region of Japan in 2011, time matters. Even with the best of warning systems, every minute counts in reducing life loss and property damage from a fast-approaching tsunami.

California's most crucial near-shore tsunami hazard is produced by the Cascadia fault zone that runs from Cape Mendocino northward along the rest of the northern California coast, and along the Oregon and Washington coasts, all the way to Vancouver Island, British Columbia. The Cascadia fault's last major rupture—a magnitude 9 earthquake in January 1700—caused at least 620 miles (1,000 kilometers) of the North American coastline to lurch upward and seaward (by about 65 feet (20 meters)).[33] This drove a wall of ocean water that reached elevations of about 50 to 60 feet (15 to 18 meters) along the California coast and also sent waves as high as 20 feet (6 meters) to strike the Japanese shores ten hours later.[34]

There is about a 1 in 10 chance that a similarly sized mega-earthquake and tsunami will occur on the entire length of the Cascadia subduction zone in the next 50 years.[35] There is also a much higher probability (around 40 percent) that the southernmost segment of the zone, and the one closest to California, will rupture in the next 50 years generating a smaller but still major, near-shore earthquake and tsunami.[36] When such events do occur, northern California coastal communities will have less than 20 minutes to react before large tsunami surges similar to the 1700 event begin to arrive.[37] It would take about an hour for waves on the order of 4 to 10 feet (1.25 to 3 meters) high to begin striking southern California communities.[38]

In southern and central California, there are several offshore fault zones that are expected to thrust the earth upward when they rupture and potentially generate a tsunami (See Figure 2). These potential near-shore tsunami sources include the Point Reyes Thrust Fault, Channel Islands Thrust Fault, San Mateo Thrust Fault, the Carlsbad Thrust Fault and Coronado Bank Fault; they are located offshore from Point Reyes, Huntington Beach and Newport Beach, and in the offshore Ventura-Santa Barbara channel area.[39] One of the best documented localized tsunamis occurred in 1927 with an earthquake occurring off Point Arguello, north of Santa Barbara.[40]

Additionally, even a moderate earthquake onshore in any part of coastal California could trigger a large submarine landslide and a more localized tsunami. In 1812, a tsunami struck the Santa Barbara and Ventura coastline after a large earthquake in the area. Although the area impacted might be more localized, there would be little warning time for such an event so close to shore. Given the density and popularity of beaches and other coastal areas, the consequences could be devastating.

Landslide-induced tsunamis are possible in steep offshore areas along the California coast, such as the offshore Monterey Canyon region and areas near Goleta and Palos Verdes, but more study is needed to understand their likelihood and extent of impact.[41]Researchers have also discovered remains of what appears to be a large submarine landslide off the Palos Verdes coast that that may have been triggered by a magnitude 7 or greater earthquake.[42] They estimate that such an event could generate localized tsunami waves ranging from 25 to 40 feet (8 to 12 meters) high.[43]

Distant Tsunami Sources

California’s coast is also at risk of tsunamis that originate elsewhere around the Pacific Ocean. Since the tidal gauge was first installed in the Crescent City harbor in 1934, it has recorded 34 tsunamis, mostly originating from distant places.[44] In the last half century, California has sustained damage, and even deaths, from tsunamis originating in the Aleutian Islands (1946), Chile (1960 and 2010), Alaska (1964), the Kuril Islands (2006), and Japan (2011). These powerful waves can arrive at

California's shores within four to 24 hours after the earthquake.

In recent decades, one of the most damaging tsunamis impacting California resulted from the magnitude 9.2 Alaska earthquake of 1964. About four hours after the earthquake, parts of northern California were struck by waves more than 20 feet (6 meters) high that flooded low-lying communities, such as Crescent City, and killed 11 people in Crescent City and 13 people statewide (see insert and Figure 6). More recently, the 2010 Chilean tsunami first struck San Diego and southern California a little more than 12 hours after the earthquake. It had a maximum tsunami amplitude of 4 feet (1.2 meters) measured at Pismo Beach, and caused over $3 million in damages to boats and docks in nearly a dozen southern California harbors.[45] The 2011 Japan tsunami began impacting California's coast nearly 10 hours after the earthquake.[46] A maximum tsunami amplitude of 8 feet (2.5 meters) was measured in the Crescent City Harbor and over $50 million in damages occurred across two dozen harbors in the state.[47] One Californian died in the 2011 Japanese tsunami.[48] Somewhat fortuitously, the 1964, 2010, and 2011 tsunamis all arrived at low-tide in California; inundation, damage, and casualties may have been significantly greater if the tsunami coincided with high-tide conditions.

In a recent study, distant tsunami sources around the Pacific Rim were analyzed to determine which were likely to have the

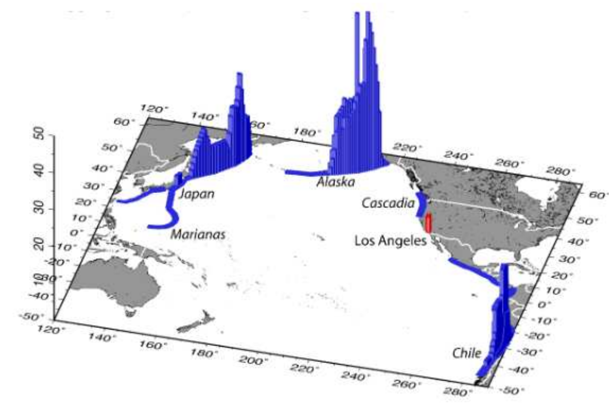


Figure 5. Map showing the disaggregation of tsunami sources around the Pacific Rim contributing to a 475-year return period tsunami peak wave height for Los Angeles *(Source: SAFRR, Chapter B, Figure 1)*

greatest impact on Los Angeles.[49] As Figure 5 shows, earthquakes occurring offshore of the Alaska Peninsula generated the highest tsunami waves along southern California shorelines.

The Science Application for Risk Reduction (SAFRR) tsunami scenario analyzes the potential impacts on the California coast of a hypothetical but plausible tsunami created by a magnitude 9.1 earthquake offshore from the Alaska Peninsula.[50] A tsunami generated by the scenario source would be larger and cause much more damage in California than the 2011 Tohoku tsunami, the Chilean tsunamis of 2010 and 1960, and the 1964 Alaska tsunami.[51] The scenario study affirms that California's experience with tsunamis over the last century is probably far from the worst that can happen.[52] There are imminent tsunami sources both near and far that could realistically cause billions of dollars in losses and substantial loss of life.

Recollections of when the tsunami from the magnitude 9.2 Alaska earthquake of March 27, 1964 struck Crescent City, California, killing 11 people

In his recent book, "The Raging Sea," (author Dennis) Powers describes a series of huge waves, most likely four, with the last being the deadliest. *"The ocean withdraws, comes barreling in 25 feet high in the fourth large deadly wave and goes inland two miles. At this time, you have tanks exploding; you have 300 buildings and businesses destroyed. You have a third of the community homeless,"* (says Powers)…

The fourth wave washes in tons of sea debris, uproots trees and rips asphalt off the streets. Houses tear away from their foundations. Cars, trucks and giant logs ram through walls of downtown buildings, but even in the light of a full moon, authorities don't immediately see the full extent of the damage… Among the shop owners who returned to the shore before the fourth wave hits is 27-year-old Gary Clawson… That night, Gary, his parents, his fiancée and two employees return to the tavern to retrieve the cash box and lock up just in case there's more flooding. Clawson recalls it was his father's 54th birthday. *"My dad, I'll never forget. He jumped up on the bar and drew himself a beer and he says, `Well, happy birthday to me.' He says, `Let it come',"* (recalls Gary Clawson). But no one knew what was about to come.

With an eerie hissing, the brackish waters rise suddenly. Clawson sees his brand-new white Pontiac Grand Prix lift up and then crash down upon his father's Dodge Dart. Dark water rushes in through the front door. Clawson yells for everyone to climb up on the bar. *"And about that time, the west wall of the building caved in and it just kind of crumpled in the middle and it took it right off the foundation. We went back probably 250 feet or so and the building hung up in the trees that were in the back,"* (describes Clawson). The tavern is bobbing like a cork in the ocean. Clawson tells everyone to get on the roof, but gasoline from a nearby storage plant is spreading in the water. The danger of a fire means the roof isn't safe; plus, Clawson's mother can't swim.

Figure **6**. Crescent City, CA after the March 27, 1964 tsunami. *(Source: W.H.Griffen, Crescent City's Dark Disaster.)*

By now they're a party of eight and a neighbor, Mac McGuire, suggests they swim out to find his small boat. Clawson agrees and they jump into the icy water. *"And we made our way through floating mobile homes and motor homes and propane tanks and stuff, and when I actually could get my foot down on something, I was right in the middle of Highway 101. It was just right up to my chin,"* (says Clawson). They soon find the boat and Clawson rows by himself over to the tavern rooftop to pick up his group. *"And I was kind of trying to cut jokes and tell my mom and dad, you know, that everything's going to be fine and whatnot. Two more rows and we'd have been on dry land but the water started receding,"* (Clawson laments).

Tsunami waves can recede just as fast as they rush in. That's what happened in Crescent City that night. The boat is spun sideways and starts heading for a tunnel under a four-lane highway. At the end of the tunnel is an iron grate that's already catching debris, cars, logs and refrigerators. The boat flips and Clawson is horrified to see his parents and fiancée thrashing in the water just ahead of him before they hit the grate. Within seconds, he hits it, too. *"I remember being just smashed just flat up against all of the debris and then I knew that I was drowning and I was saying to myself, `Oh, my gosh, I can't believe it.' So I took one chance and I knew I couldn't go up,"* (Clawson recalls). Clawson pushes down, hits bottom and the pressure forces him through two of the steel pilings. His father, mother, fiancée and two employees don't make it. Six other people died in Crescent City that night, including two small children.

How Does Tsunami Risk Compare to Other Hazards?

Since the disastrous 2004 Indian Ocean tsunami, there have been a sequence of devastating tsunamis around the world, including the Kuril Islands (2006), Samoa (2009), Chile (2010), and Japan (2011), causing over one-quarter million deaths and hundreds of billions of dollars in property and societal losses. All this from a natural hazard previously thought to be rare.

Likewise, in California, tsunami hazard along the coast was, until recently, perceived to be fairly moderate.[53] In the past decade, research has found that the potential near-source tsunami risk along the Cascadia Subduction Zone is far greater than previously thought.[54] There is also a far better understanding of the historic frequency of major tsunamis and improved methods for modeling of tsunami wave heights and potential inundation areas.[55]

A recent comprehensive analysis of the recurrence rates and probabilities of thousands of tsunamis, from sources around the Pacific Ocean, found that the frequency of damaging tsunami waves striking the California coast from major earthquakes, like a magnitude 9.1 Alaska earthquake, is on the order of a hundred to a few hundred years (see Figure 7). What this means is that the likelihood of a major tsunami impacting the California coast is comparable to the probability of great floods impacting California's Central Valley, or a great earthquake occurring along the southernmost segment of our active San Andreas Fault.

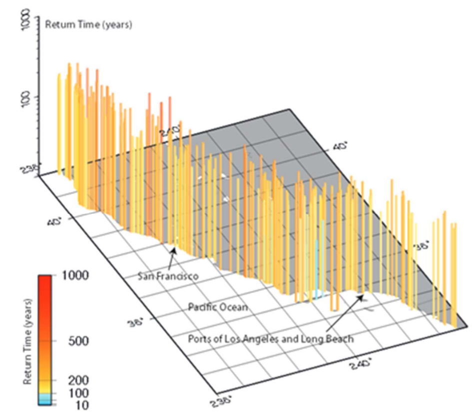


Figure 7. Map of the California coast with bars at individual locations showing the frequency interval of tsunamis with offshore amplitudes equivalent to or larger than the amplitude simulated for tsunami scenario for the magnitude 9.1 Alaska peninsula earthquake of the SAFRR tsunami scenario *(Source: SAFRR, Chapter A, Figure 3, p. 15).*

What Needs to Be Done to Address California's Tsunami Risk?

For more than a decade the California Office of Emergency Services (Cal OES) and the California Geological Survey (CGS) have partnered to form the California Tsunami Hazard Preparedness and Mitigation Program (referred to hereafter as the "state tsunami program") to help California's coastal communities better prepare against the impact of tsunamis. The state tsunami program is primarily supported by a grant from the National Ocean and Atmospheric Administration's (NOAA), National Tsunami Hazard Mitigation Program (NTHMP); the state program does not presently receive support from the California state government.

California has also been a participant in the national TsunamiReady® Program, which is designed to help cities, towns, counties, universities, and other large sites in coastal areas reduce the potential for disastrous tsunami-related consequences.[56] To be designated “TsunamiReady®,” a community must meet certain criteria for communications and coordination, preparedness, and administration of a formal tsunami hazard operations plan. [57] As of March 6, 2014, there are 38 TsunamiReady® sites in California, 21 of which are cities, eight are counties, five are military sites, parks, or special districts (e.g. school and fire districts), two are Indian tribes and there is one university and one commercial site.[58]

One of the state tsunami program’s first projects mapped the potential tsunami inundation areas along the California coast. These maps have proven to be immensely helpful to local and state emergency planning and for evacuating residents when recent tsunami warnings were issued.[59]

Information gathered from recent tsunami disasters in Chile (2010), Japan (2011), and elsewhere has also informed the state tsunami program’s work, and it is now developing new mapping tools that will serve as the basis for a new suite of derivative products for emergency response, maritime, and land-use planning and also provide new design guidance for engineering and construction.[60]

Until 2012, California and other states were guaranteed funding from the NTHMP under federal Tsunami Warning and Education Act of 2006. Since the Act expired and has not yet been reauthorized by Congress, the level of annual funding from the NTHMP has dropped substantially, making it difficult for the State to maintain the essential program work and adequately address the needs of the emergency management, maritime, land use and building communities.

In 2010, the California Tsunami Policy Working Group (CTPWG) formed to identify, evaluate and make recommendations to resolve issues that are preventing full and effective implementation of tsunami hazard mitigation and risk reduction in California’s coastal communities. This voluntary ad hoc advisory body is composed of experts in earthquakes, tsunamis, flooding, structural and coastal engineering, urban planning, and natural hazard policy. The CTPWG has considered lessons learned from recent tsunamis and looked at research and “best practices” in California and around the world to identify and prioritize needed improvements.

Part B of this report identifies 47 actions that the CTPWG recommends be taken to significantly reduce the impact of future tsunamis along California’s coastline. They are organized around three goals to:

1) Build a solid foundation from mitigation; 2) Practice risk-based land-use and construction; and 3) Enhance emergency management. They are also grouped by related topics and in many cases are mutually supportive. Together, they also provide a framework of action that coastal areas elsewhere in the world can undertake to reduce their vulnerability to tsunami hazard.

The preceding discussion is but a summary. To venture deeper into the latest perspective on California's tsunami risk, the reader is encouraged to examine reports of the *SAFRR Tsunami Scenario Project* [61] and the assessment: *Community Exposure to Tsunami Hazards in California.*[62]

PART B - RECOMMENDATIONS FOR REDUCING TSUNAMI RISK

The following is a list of recommendations that have resulted from deliberations over the past 24 months of the California Tsunami Policy Working Group (CTPWP). Members of the working group are recognized experts in the fields of natural hazards, flood hazards, emergency management, local and regional land-use planning, structural and coastal engineering, and geological/seismological and ocean sciences. Their first task identified gaps and roadblocks in coastal community efforts to mitigate tsunami hazard. Next, the group ranked findings according to how severely they prevent communities from achieving effective hazard mitigation. Finally, steps were taken to resolve the most important problems taking into consideration the recommended action's viability and potential to evoke community resistance be it a mandate (high conflict), encouraged action (moderate conflict) or an entirely voluntary action (low conflict potential).

For those interested in knowing more about the California Tsunami Policy Working Group, its formation and operations have been recently documented.[63]

The recommended actions are organized around three principal goals: 1) *Build a Strong Foundation for Mitigation*; those actions that must be undertaken to most effectively implement many of the other recommended actions*, 2) Practice Risk-Based Land-use and Construction*, and 3) *Enhance Emergency Management*. Each is accompanied by an overview that provides the goal's rationale, followed by three or four objectives for reaching the goal (See Figure 8). Beneath each objective lies a brief description of problems hindering tsunami risk reduction followed by resolutions in the form of recommended actions. Each problem and recommendation is numbered for easy reference.

A Framework to Reduce Tsunami Risk

Build a Solid Foundation for Mitigation

Comprehensively Assess Tsunami Hazard Likelihood and Severity – Develop the capability to estimate the likelihood and severity of tsunami inundation along the California coast.

Improve Our Understanding of Tsunami Risk and Ways to Reduce it – Improve knowledge of tsunami damage potential and how to motivate actions to reduce it.

Establish a Framework to More Effectively Communicate Tsunami Warnings – Capitalize on mobile and cellular network technologies and infrastructure.

Capitalize on National Efforts to Reduce Tsunami Risk – Support continuation of tsunami hazard mitigation, education and funding at the national level.

Practice Risk-Based Land-Use and Construction

Establish State-designated Tsunami Hazard Zones – Integrate tsunami hazards into appropriate land use planning and building construction policies and codes.

Condition Development in Areas Exposed to Tsunami Hazards – Modify existing policies to ensure safe placement and construction of the built environment.

Implement Tsunami Resilient Building Codes – Support development and adoption of tsunami design standards within tsunami hazard zones.

Consider Tsunami Hazard in Land-Use Decisions – Utilize knowledge of tsunami hazard in state and local land-use planning and decision-making.

Enhance Multi-Jurisdictional Planning for Tsunami Hazard – Facilitate cooperative planning among adjacent jurisdictions to address broad regional issues and potential impacts to lifelines and other shared infrastructure.

Enhance Emergency Management

Increase the Effectiveness of Tsunami Hazard Warnings – Support development of rapid clear, action-oriented tsunami hazard warnings, evacuation notices, and other critically important messages.

Improve Regional Tsunami Preparedness, Response, and Recovery – Facilitate coordination among adjacent jurisdiction emergency planning activities.

Prepare the Maritime Sector for Tsunami Hazards – Fortify the capacity of California's recreational and commercial maritime communities to withstand the impacts of tsunamis.

Figure 8. A Framework to Reduce Tsunami Risk

Goal 1- Build a Strong Foundation for Tsunami Hazard Mitigation

Overview

Many of the actions needed to reduce future tsunami loss depend upon having a stronger underlying tsunami policy and program foundation that enables and supports implementation. A strong foundation for policy action includes: 1) an accurate understanding of tsunami hazard and risk along California's coastline, 2) an investment in continuing research, 3) an established network infrastructure for dissemination of tsunami warnings, and 4) federal, state, and local intergovernmental coordination to facilitate consistency in tsunami hazard mitigation. These components are considered foundational: they must exist before other risk reduction actions can become truly effective. Reducing the risk of tsunamis requires difficult decisions that have economic, political, and sociological costs and benefits. With limited resources available, tradeoffs must be made among a community's other safety, financial, and social priorities. A clear understanding of the hazard and potential consequences is necessary to ensure tsunami hazard mitigation can find its proper place among other pressing needs. Assessing tsunami hazard along California's coastline is key to making a realistic assessment of risk.

The scientific understanding of the threat presented by tsunamis continues to grow and unfold. Continued investment in research is a crucial component to improving and prioritizing policy actions. This includes further study of hazard and risk, as well as research on social behaviors in emergency situations that can help improve communication of emergency response procedures.

Equally important to the foundation of a strong tsunami hazard mitigation policy is an effective communication system. The tsunami warning centers operated by the National Oceanic and Atmospheric Administration (NOAA) provide a valuable public safety service. However, it remains a challenge to effectively and immediately communicate official warning messages to the public which result in the appropriate life-saving actions. Today's mobile communication technologies and existing infrastructure affords the opportunity to significantly improve focused dissemination of tsunami warnings, but it must be enabled to do so.

Finally, state and local efforts to mitigate tsunami hazards and coastal impacts of climate change could be better coordinated, with oversight at the national level. Nearly the entire coastline is exposed to tsunami risk and climate-induced sea level rise. Inundation and key exit routes do not stay neatly within administrative boundaries, while all government levels have responsibilities regarding emergency response. Strong working relationships and coordination between levels of government serve as an important basis for policy action.

Together, a state-of-the-science assessment of tsunami hazards, a technologically-advanced backbone for dissemination of warnings, an investment in research that focuses on improving the capacity to adapt, and integrated government frameworks would form a solid foundation for protecting California's coastal communities from occasional, but potentially catastrophic tsunamis.

Comprehensively Assess Tsunami Hazard Likelihood and Severity

The range of severity, the likelihood of occurrence, and potential impacts along California's coastline from tsunamis must be determined to provide a strong foundation for policymaking. Both major sub-oceanic earthquake-generating faults bordering the Pacific Rim and local offshore landslides are potential sources of tsunamis, each with different policy implications. The size and destructive potential of a tsunami depends on the amount of water displaced. This varies with earthquake magnitude and the resultant displacement of the ocean floor or the volume of sediment involved in a submarine landslide. Every coastal location, as well as each possible magnitude of a tsunami, has a unique average frequency of occurrence that allows estimates to be made of how likely such an event is to occur.

For each event under consideration, the tsunami's travel through the ocean and the landward extent of flooding upon reaching the coastline must be modeled. The flow depth of inundation, flow patterns, and current velocity are all factors that help estimate the potential destructiveness of a tsunami flood event. Such modeling requires large volumes of data to accurately characterize the shape and topography of the ocean floor and coastal land surface, and large-scale computing to model the characteristics of inundation flow. Modeling allows a city or county to overlay model results on their infrastructure and estimate potential impacts and losses. Information on where damage will occur, combined with estimates on the probability of occurrence, makes it possible to explore the benefits and costs of mitigation. Decisions are then possible as to what levels of risk are acceptable or unacceptable, as well as those that are undesirable but may be tolerable. Tradeoffs can be considered that can lower the tolerable risk to as low as reasonably practicable.

PROBLEM 1 – Current federal and state-funded modeling tools may not be accurate enough to provide the detailed, reliable information needed for public policies such as building codes and land-use regulations. There are several possible sources of error: inaccurate model inputs that incorrectly characterize the generating earthquake or landslide and their frequencies of occurrence; inaccuracies in describing ocean bottom terrain and the land surface subject to flooding; and limitations in the models themselves in their representation of the natural processes involved in tsunami generation and propagation. Models that only estimate the degree of tsunami-induced flooding have undergone validation as part of the peer review and vetting process. However, models that also estimate the likelihood or probability of such impacts are a more recent development and have not undergone a similar validation effort.

- **RECOMMENDATION 1.1 – Support development and evaluation of advanced tsunami hazard assessment models.** Their results must be vetted before they can be used as a reliable basis for public policies. It is important that products are accurate, easy to use, and consistent across jurisdictional boundaries. Guidelines for standardized testing and evaluation of tsunami hazard models (intended for use in public policymaking) should give consideration to a model's:
  - *conceptualization* (appropriateness of the model physics and characterization of tsunami sources and other input parameters, and treatment of uncertainty),
  - *verification* (assurance that mathematical coding of the model is correct),
  - *validation* (comparing model components deterministically against case histories), and
  - *reporting standards* (regarding the reliability of the model output for tsunami risk-reduction decision-making).

- **RECOMMENDATION 1.2 – Require that tsunami hazard models used to estimate tsunami and seiche inundation hazard for public policy purposes are: peer-reviewed and tested, published in professional peer-reviewed literature, or are otherwise professionally recognized as "standard-of-practice."** Such requirements could also be considered for models used to estimate inundation from sea level rise and weather-related ocean storm surge, riverine, alluvial fan and flash flooding.

- **RECOMMENDATION 1.3 – Require all computer software used to model inundation and develop public policy guidance to be open and fully transparent to permit full and effective testing and evaluation.**

- **RECOMMENDATION 1.4 – Expand the test program administered by the National Tsunami Hazard Mitigation Program (NTHMP) to include an evaluation of all models used to estimate the likelihood and severity of tsunami inundation.** If this cannot be accomplished by the NTHMP, then a comparable program needs to be established.

PROBLEM 2 – California has historically focused tsunami preparedness activities and response planning within the land-based sector of coastal-communities – primarily through the promotion of onshore, inland evacuation planning. Little has been done, however, to foster preparedness and response planning within the maritime sector, which has the greatest exposure and lies first in line of harm's way. There is a fundamental need to better understand the unique hazard tsunamis create within ports, harbors and marinas.

- **RECOMMENDATION 2.1 – Analyze the tsunami hazard within ports, harbors and marinas focusing on high-current velocity, turbulence, eddies, and other hazardous conditions to identify high-hazard areas.** Hazard maps could then be prepared for the approximately 70 harbors and bays in California. Such information can be used by harbor authorities to improve in-harbor navigation routes, reduce exposure, and increase the resiliency of harbor facilities against tsunami hazards.

  RECOMMENDATION 2.2 – Determine, in a consistent manner, the seaward extent of hazardous wave action along California's coast. This will identify limits beyond which vessels would be free from tsunami impacts. With this zone identified, partner agencies and stakeholders could collaborate to designate a "safety line" on coastal charts and maps as they are revised. The updated maps can be broadly publicized to include specific target audiences, such as military, transport, and cruise ships, commercial fishing boats, and recreational boaters, as well as port, wharf, dock and marinas managers.

Improve Our Understanding of Tsunami Risk and Ways to Reduce It

When compared to other natural hazards affecting California, tsunamis represent a rare, but high-risk threat to coastal development. Because the time between large, potentially catastrophic events measures in hundreds to thousands of years, the threat has been considered a low priority for scientific research, preparedness, and mitigation. Recent worldwide destructive tsunamis such as the 2004 Indonesia disaster, where devastated island communities had no written history of such an event, have underscored the need to focus research on how to better characterize the hazard, understand how the built environment can enhance tsunami flow, better understand human behavior to increase public awareness and motivate tsunami preparedness and mitigation actions in California. Currently only 35% of coastal counties and 20% of incorporated cities are designated TsunamiReady®.

PROBLEM 3 – Tsunami flood modeling does not currently account for the influence of the built environment on water flow patterns and currents. Forces can increase significantly around buildings, increasing a tsunami's capacity to cause damage. Research on these effects can improve inundation modeling, lead to better risk assessment, and help improve the design of tsunami-resilient structures. Until this phenomenon is better understood, it cannot be appropriately addressed in tsunami building codes, design and construction practices.

- **RECOMMENDATION 3.1 – Research the hydrodynamic effects of existing development and proposed locations of future development on flow velocity and consequent structural loading during tsunami inundation, as well as ways to account for these effects in the engineering design process.**

PROBLEM 4 – Local risk reduction requires support from community leaders: city councils, special districts, county boards of supervisors, and the public. Tsunamis are a rare phenomenon and are not generally part of a community's experience. Consequently, there is a tendency for society to focus on pressing short-term issues and neglect preparation for the longer-term ones.

- **RECOMMENDATION 4.1 – Identify ways to provide incentives for cities, counties, and special districts to become TsunamiReady®.** Also, explore incentives that would encourage the private sector to undertake similar preparedness activities.

Establish a Framework to More Effectively Communicate Tsunami Warnings

Cell phones are one of the most widely-used forms of personal communication in the U.S. Existing cellular networks present an opportunity for more effectively disseminating hazard warnings and related information to the affected population.

PROBLEM 5 – Existing cellular networks are currently focused on meeting the demands of customers based on service load, rather than establishing provisions for emergency notifications. There is a need to establish an emergency protocol that rapidly transforms private cellular networks into a dedicated backbone for the issuance of emergency communications regarding hazard warnings.

- **RECOMMENDATION 5.1 – Expedite efforts already underway to establish agreements between government agencies that issue warnings and cellular network providers.** It must become a priority to shape network capacity to reach as much of the affected public as possible during a disaster.

Capitalize on National Efforts to Reduce Tsunami Risk

NOAA's National Tsunami Hazard Mitigation Program provides broad guidance and fiscal support for tsunami hazard mitigation and facilitates intergovernmental coordination. It provides support for pilot studies, model validation, incentive programs like TsunamiReady®, and operation of the tsunami warning centers.

PROBLEM 6 – Under current fiscal constraints, the National Tsunami Hazard Mitigation Program's future is uncertain. The value and importance of the national program to the goal of protecting the nation's coasts must be heard.

- **RECOMMENDATION 6.1 – Support reauthorization of the federal Tsunami**

Warning and Education Act and continue to assist coastal communities in becoming TsunamiReady®.

The importance of the preceding recommendations cannot be overstated, as they lay the necessary foundation for many of the mitigation actions that follow.

Goal 2 - Practice Risk-Based Land-Use and Construction

Overview

Avoidance is among the more effective risk-reduction strategies for natural hazards. Placing new buildings in non-hazardous areas or reducing a hazard's impact by increasing the resiliency of engineered structures through tsunami-resilient construction can significantly reduce risk. Determining which strategy to use depends on the need and the added cost to safely locate a structure in a hazardous area, when compared to moving the project to a safer location. Such decisions are dependent on detailed knowledge of location and severity of hazards as well as enforcement of tsunami resilient building codes and practices.

Progress is being made to develop new building codes for critical structures but gaps still remain in guidance for the development and construction of other building types. The Subcommittee on Tsunami Loads and Effects of the American Society of Civil Engineers (ASCE) are developing new, detailed building guidance that could be included in the 2016 edition of ASCE 7 - Minimum Design Loads for Buildings and Other Structures, and possibly in the building codes that follow, such as California's code update in 2018. The focus of the Subcommittee's new guidance is on addressing tsunami loads (forces) on Risk Category II (moderate to high occupancy) buildings of structural height greater than 65 feet (19.8 meters) and Risk Category III (high occupancy and essential facilities) and IV (critical facilities) buildings. Even if these new requirements are accepted into the 2016 ASCE 7 and the 2018 update of the California Building Code, standards and/or guidance will still be needed for designing Risk Category II structures less than 65 feet as well as the more typical types of lower occupancy residential and commercial buildings common along the California coast. These gaps will need to be addressed through additional tsunami design standards and land-use planning tools to improve community resiliency.

Condition Development in Areas Exposed to Tsunami Hazards

The California Coastal Commission and local governments have begun to incorporate tsunami-specific requirements for coastal development through the Local Coastal Program certification process; however, additional planning and implementation tools are needed.

PROBLEM 7 – Current State-issued tsunami hazard zones are designed to provide guidance for emergency response planning, but they are not precise enough for practical use in regulating coastal land use and development. They are worst case scenarios that do not consider the probability of these events. Decisions for land use planning, zoning, and construction benefit from knowing the likelihood of various levels of hazard severity and risk, especially when weighing the benefits and costs of structural design against other mitigation options.

Such decisions also must consider tsunami hazard not only in terms of inundation area, but also in terms of engineering parameters that allow calculation of potential physical loads placed on structures. Tsunami hazard zones for use in developing land-use plans, zoning ordinances and construction decision-making must be prepared specifically for those purposes.

- **RECOMMENDATION 7.1 – Establish State-designated tsunami hazard zones appropriate for application to land-use planning and tsunami resilient building codes that are currently under development.** This work should be done in close consultation with local planning and building departments, as well as those entities responsible for developing provisions for tsunami resilient design in model building codes. Consideration should be given to a two-level approach: 1) probabilistic analysis of hazard from distant and nearby by Pacific Rim sources, and 2) deterministic analysis of hazard due to near-source high-consequence events that are possible, such as submarine landslides.

- **RECOMMENDATION 7.2 – Form an advisory committee to guide development of mapping criteria to be used in delineating State-designated tsunami hazard zones and the guidelines for local agencies to use in implementing the zones.** The committee should be comprised of qualified individuals with expertise in geology, seismology, tsunami modeling, civil, coastal, and structural engineering, local and regional planning, and insurance. The hazard zones should be appropriate for land-use decisions and the mapping criteria should be "all-hazards" based and delineate thresholds of acceptable, tolerable, and intolerable likelihoods and associated consequences. In other words, decisions for land use planning, zoning, and construction should be risk-based, balancing the target performance level (annual probability of failure) with the associated consequences.

- **RECOMMENDATION 7.3 – Establish special State-designated tsunami hazard zones that would trigger risk-based design and construction of new critical facilities, essential services facilities, and infrastructure**. Such facilities include those that receive, store, generate, process and distribute hazardous materials (e.g. chemical plants and oil and gas refineries and terminals). These hazard zones should also be risk-based, balancing the target performance level (annual probability of failure) with the associated consequences. Trigger requirements for retrofit or relocation of existing critical facilities, essential services facilities and infrastructure should also be considered. All these facilities are crucial to a community's safe recovery and warrant special protections.

- **RECOMMENDATION 7.4 – Modify the existing framework of the Seismic Hazards Mapping Act (Public Resources Code, Chapter 7.8, Sec. 2690 et seq.) to include site-specific tsunami hazard investigations consistent with those to be specified in tsunami building code provisions.** The associated regulations (California Code of Regulations, Title 14, Division 2, Chapter 8, Article 10) should be amended to include designation of tsunami hazard zones of required investigation, and include necessary changes to a) mapping requirements, b) review of designated tsunami hazard zones, c) criteria for approval of project site-investigation reports (including qualifications for signature authority), d) report requirement waivers, and e) guidelines for conducting required site-specific investigations of tsunami inundation hazard. In addition to practical advice on state-of-practice methods of assessing local tsunami hazard, the guidelines could also offer cautionary advice on the hydrodynamic effects of amplified flow depth and current velocity caused by existing structures adjacent to the project site, and the resulting potential for enhanced loads and foundation scour on the proposed construction, as well as the effect of the proposed construction on existing structures.

- **RECOMMENDATION 7.5 – Amend California's natural hazards disclosure law (California Civil Code Sec. 1103 et seq.) to require buyers of real property to be notified if located in a State-designated tsunami hazard zone.**

Implement Tsunami Resilient Building Codes

The current California Building Code (CBC) contains provisions for weather-related, flood-resilient design. In addition, nearly all coastal communities participate in the National Flood Insurance Program (NFIP), which requires adherence to specified flood design standards (Title 44 U.S. Code Part 60, NFIP Regulations).

PROBLEM 8 –The current International Building Code (IBC) and National Flood Insurance Program (NFIP) flood design standards do not consider the unique character of tsunami-induced flooding except for special tsunami evacuation structures. Design standards for other types of buildings are inadequate to resist the increased loads on structural systems and enhanced scour of engineered foundations that tsunamis are capable of causing.

❖ **RECOMMENDATION 8.1 – Amend existing design and construction codes to include the risk-based assessment of anticipated tsunami forces and their impacts on proposed structures and project sites, and develop provisions that meet pre-defined performance standards.** Such work is currently underway by the Subcommittee on Tsunami Loads and Effects of the American Society of Civil Engineers (ASCE), but results are not anticipated until the 2016 edition of ASCE 7 recommended provisions are released, and subsequently incorporated into the 2018 edition of the IBC. Upon release of ASCE 7 guidelines for tsunami construction, the California Building Standards Commission should, as an immediate stopgap, adopt the recommended tsunami resilient design provisions using the California Building Code's interim revision process.

❖ **RECOMMENDATION 8.2 – Increase the ISO Building Code Effectiveness Grading Schedule (BCEGS) rating based upon adoption of tsunami resilient provisions into community building codes**. This could increase future disaster recovery funding available for communities while also providing a financial incentive for tsunami resilient construction. ISO administers the BCEGS, which assesses and rates both building code adoption and enforcement practices for a community's resilience against natural disasters. The rating can affect the availability of federally backed loans and disaster assistance grants. If a community rebuilds to current code levels during post-disaster recovery, responsibility for the cost differential may fall on the community as FEMA would only cover cost of restoring a structure to the code level in place at the time of the disaster.

❖ **RECOMMENDATION 8.3 – Support continuation of the California Geological Survey's work with the ASCE Subcommittee on Tsunami Loads and Effects to develop prototype probabilistic inundation maps from local and distant tsunami sources to assist in the development of tsunami building code provisions.**

❖ **RECOMMENDATION 8.4 - Require State-designated tsunami hazard zones under the Seismic Hazards Mapping Act (Public Resources Code Sec. 2690 et seq.), to be compatible with those used to trigger tsunami building code provisions**. In addition to triggering tsunami design requirements for proposed construction, existing statutes would also require a site-specific investigation of associated geotechnical hazards and a plan to mitigate identified hazards before issuance of building permits.

PROBLEM 9 – Experience throughout the state from enforcement of seismic provisions in the California Building Code indicates that there exists a wide variation in the quality and reliability of site-specific estimates of seismic loads for design purposes that stem from the technical qualifications, education, and experience of those performing the work. There is a need for tsunami hazard professional education and established standards against which those in the capacity to perform regulatory review of engineering design plans can compare the results of site-specific estimates of tsunami design loads in the construction permitting process.

- **RECOMMENDATION 9.1 – Include the broad topic of tsunami hazard in college curricula, licensing, and continuing education in coastal engineering, structural engineering and civil engineering.** Course offerings would include, but not be limited to, tsunami source generation, propagation, and the theory and application of hydrodynamic inundation modeling, its limitations, sources, and treatment of uncertainty. Because the science and engineering of tsunami hazard is comparatively new and evolving, career education could include short refresher courses.

- **RECOMMENDATION 9.2 – Encourage incorporation of tsunami hazard and engineering in the certification program for coastal engineering provided by the Academy of Coastal, Ocean, Port & Navigation Engineers (ACOPNE).**

- **RECOMMENDATION 9.3 – Establish guidelines for the formal certification of coastal engineers as a specialty within civil engineering.** Certification will help provide quality assurance for site-specific tsunami inundation and engineering analyses that will be required once tsunami provisions are incorporated into the California Building Code.

- **RECOMMENDATION 9.4 – Support development of additional tsunami hazard products that may be required to implement tsunami code provisions.** For instance, local governments could benefit from default regional inundation parameters that can serve as a baseline for evaluating estimates made by the developer during the review and permit approval process for projects within a State-designated tsunami hazard zone.

Consider Tsunami Hazards in Land-Use Decisions

The California Coastal Commission has authority over land use and development within the State-designated “coastal zone.” The zone varies in width, extending from the shoreline inland 1000 feet to 5 miles or more, and is based on the California Coastal Act’s primary intent to protect environmentally sensitive areas along the coast from development and to ensure the public’s right to coastal access.

PROBLEM 10 – A new analysis of tsunami hazard along California's coastline indicates that in some locations flood hazard extends landward well beyond the official coastal zone boundary, limiting the California Coastal Commission's authority to mitigate the hazard and risk.

- **RECOMMENDATION 10.1 – Require that any tsunami resilient building code provisions included in the California Building Code be applied throughout the full geographic extent of State-designated tsunami hazard zones.** This includes areas within and beyond coastal zones defined by the California Coastal Act. Enforcement would lie under the authority of Title 24 of the California Code of Regulations. This should be viewed as a minimum level of action and communities wanting to implement more stringent standards should be supported to do so.

- **RECOMMENDATION 10.2 – Amend state general plan laws and programs to require consistent recognition and application of State-designated tsunami hazard zones within the hazard identification and risk assessments of the State Hazard Mitigation Plan, Local Hazard Mitigation Plans, Local Coastal Programs, and local general plans.** This should be viewed as a minimum level of action and communities wanting stronger land use policies and broader consistency applications should be supported to do so.

- **RECOMMENDATION 10.3 – Amend California law to include financial incentives that encourage coastal communities to adopt consistent land use policy within State-designated tsunami hazard zones, integrating mitigation policies, strategies, and actions of their Local Coastal Program land-use plans, local general plans, and Local Hazard Mitigation Plans.**

Enhance Multi-Jurisdictional Planning for Tsunami Hazard

Tsunamis can inundate large, low-lying areas, affecting multiple jurisdictions and the lifelines that serve them. Service interruptions of transportation networks, fuel, water, sewage, electric power, telephone, cable, fiber optics, flood control systems, and other broadly-distributed lifelines can become regional issues in major flood events. Similarly, other categories of broadly-distributed critical facilities located along the coast that are essential to recovery operations following a disaster also warrant special consideration in hazard mitigation plans.

PROBLEM 11 –Many safety and hazard mitigation plans are prepared by and focus on single jurisdictions, and lack a regional perspective on issues that can cross jurisdictional boundaries. While the emerging national, state, and local attention on climate change adaptation is facilitating more inter-governmental and inter-jurisdictional coordination, more cooperation is still needed.

- **RECOMMENDATION 11.1 – Support the development of comprehensive multi-jurisdictional, multi-hazard mitigation plans that work to resolve inconsistencies among adjacent jurisdictions**. This should include facilitating greater connectivity between the State Hazard Mitigation Plan, regional transportation plans, multi-jurisdictional and Local Hazard Mitigation Plans, Local Coastal Programs, and local general plans. This will help resolve broad regional issues and develop more uniformly effective protection against tsunamis.

- **RECOMMENDATION 11.2 – Incorporate tsunami hazards into regional land–use planning and strategies to mitigate climate impacts, such as increasingly intense coastal storms, coastal flooding, and sea level rise.** Sea level rise is now a factor for coastal land use planning recognized by the State of California in the State Hazard Mitigation Plan, and multiple other statewide and regional plans dealing with climate adaptation planning. Land use strategies to mitigate the impact of climate change can be relevant to long-term land use mitigation solutions for tsunami inundation. Also, including tsunami hazards into analyses could increase the benefits of certain mitigation strategies.

Goal 3 - Enhance Emergency Management

Overview

Alternative mitigation strategies to reduce the immediate threat from tsunamis must be considered in order help reduce the threat to heavily developed coastal areas that are unlikely to undergo redevelopment in the near term. First and foremost is the protection of public safety via effective emergency management. Existing populations must receive timely warnings and carefully planned instructions for safe and effective evacuation and a clear message on when it is safe to return. In a destructive tsunami, recovery can be enhanced by advanced planning for restoration, operational recovery, and business resumption. Particularly at risk is the maritime sector which, by virtue of its location on or near the water, has the highest exposure to tsunami hazard and risk. Damage and business interruption to California's major ports and harbors can have severe consequences on local, state, and national economies. An opportunity exists to improve the effectiveness of warnings, response and recovery, and significantly reduce the impact of rare, but potentially catastrophic tsunamis.

Increase the Effectiveness of Tsunami Hazard Warnings

Audible sirens are one of the current means of alerting the public of an advancing tsunami. Additional, and purposefully redundant, notification methods include use of the Emergency Alert System (TV/radio) and activation of the NOAA Weather Radio, Telephone Emergency Notification Systems (TENS) (e.g. Reverse 911), Civil Air Patrol on-board aircraft audio broadcast systems, and door-to-door notification by first responders (e.g. law enforcement and fire). Experience in the 2011 Tohoku, Japan tsunami demonstrated the potential effectiveness of broadcasting evacuation warnings through cellular networks. Most, if not all, California counties currently implement a residential telephone emergency notification system, such as the TENS or Reverse-911. These have limitations, however, as these systems are designed to reach landlines and require a person to be home to answer.

PROBLEM 12 – Experience during the 2011 Japanese tsunami demonstrated the need to improve the procedures for issuance and local dissemination of tsunami hazard warnings. The National and Pacific Tsunami Warning Centers are currently improving and standardizing how warnings are disseminated to state and local agencies in the U.S., guided by the reports of confusion by warning recipients, contention in web access, and other issues during the 2011 Japanese tsunami. More, however, needs to be accomplished.

- **RECOMMENDATION 12.1 – Continue support for the development and full implementation of the FEMA-FCC-wireless carrier partnership and application of regional broadband public safety networks in California.** The partnership is working to provide warning information through Wireless Emergency Alert (WEA)-capable mobile devices as well as for the TENS (e.g. Next Gen 911 and Reverse 911 systems). The capability to focus messages to specific regions and therefore preventing unnecessary disruptions to unaffected areas would also be beneficial.

- **RECOMMENDATION 12.2 – Develop standardized mobile phone applications that allow receipt of tsunami evacuation warnings from local emergency services agencies.** Such applications could contain basic forecast information received from the national warning centers, as well as locally-derived instructional information that could assist evacuations by providing safe routing to the nearest designated safety areas using web navigation services and GPS. Suggested cell phone applications could test capabilities by targeting the same audience currently being served by the existing TENS.

PROBLEM 13 - After receiving notification from the National Tsunami Warning Center, and proceeding with evacuation, local response agencies are left with the responsibility to issue an "all clear" message that allows evacuees to return to their prior locations. Input from local response agencies confirm that they currently lack adequate guidance upon which to pass judgment on whether to issue an "all clear."

- **RECOMMENDATION 13.1 - Develop guidance for local response agencies to determine when to issue the "all clear" following tsunami alerts.** Additional guidance could be provided through hazard updates or other timely assessments.

- **RECOMMENDATION 13.2 – Continue Live Code (end-to-end) communications tests of the Emergency Alert System to ensure that the tsunami warning can be effectively and properly delivered during an actual event.** This can be achieved by establishing a formal agreement between commercial broadcasting and government emergency management operations, with approval by the FCC and cooperation and planning support of NOAA National Weather Service offices, Cal OES, local broadcasters, county emergency managers, and others. This testing could be expanded to occur throughout coastal California. Alternatively, additional tests of the system are already being planned annually statewide via NOAA.

Address Regional Preparedness, Response, and Recovery Issues

Tsunami resilient design and construction standards are under development; however, a community that is currently exposed to tsunami hazard is particularly vulnerable because existing neighborhoods, commercial districts, industrial parks and infrastructure have not been built to withstand the destructive forces of tsunamis. Under such conditions life safety is of paramount importance, which places effective emergency management at the forefront of risk-reduction strategies. NOAA's tsunami preparedness program designates communities as "TsunamiReady®" when they have met a broad spectrum of emergency management and preparedness requirements for tsunami hazard. Guidelines for the program consider whether the community has appropriate activities and capabilities in the areas of communications and coordination, tsunami warning reception and local dissemination, community preparedness, and administrative goals. An analysis of the status of California's coastal communities reveals that although tsunami inundation maps are available and emergency response planning is currently underway, much more can be done to enhance community-level preparedness. Of the 20 at-risk counties in California, only 35% are designated TsunamiReady® and only 20% of the 94 at-risk incorporated cities have achieved the designation.

Cal OES coordinates implementation of the Tsunami Ready® program with support from NOAA's National Tsunami Hazard Mitigation Program and has found that some Tsunami Ready® designated communities have not met the guidelines equally effectively. A series of workshops with local emergency services agencies identified several issues and product needs that could significantly improve preparedness and response. There is also a need to improve coastal community participation in the TsunamiReady® Program and clarification of standards for more consistent program implementation.

PROBLEM 14 – A recent workshop conducted by Cal OES with local emergency response agencies found that there is a tendency for communities to implement provisions of TsunamiReady® and develop response plans without coordinating with adjacent communities. This has resulted in considerable variability in response effectiveness from one community to another. As with regional land-use strategies for hazard mitigation, there is also a need to better coordinate tsunami preparedness and response activities among coastal communities.

- **RECOMMENDATION 14.1 – Continue to support the State and local partnership for coordinated and consistent implementation of the TsunamiReady® program in coastal communities.** This includes operation of the program steering committee, advisory services to local response agencies, assistance in warning sign placement in tsunami hazard zones, and public outreach.

- **RECOMMENDATION 14.2 – Establish a dedicated web service to share tsunami preparedness and response activities among coastal communities.** Information could include GIS-enabled sharing of evacuation maps, evacuation plans, online training for emergency response employees, model response guidelines, and playbooks for various hazard inundation scenarios to help local agencies scale their responses to tsunami hazard notifications issued by the National Tsunami Warning Center.

- **RECOMMENDATION 14.3 - Help regional associations of governments to collaborate with California's coastal cities and counties in inter-jurisdictional preparedness, response, and recovery planning.** A multi-jurisdictional plan allows participating communities to adopt relevant regional goals and action plans, while sharing community-specific goals and actions with other cities. Much can be gained by sharing program activities and providing consistent messages in education and outreach activities across communities.

- **RECOMMENDATION 14.4 – Conduct a comprehensive and coordinated scenario-based vulnerability assessment of critical facilities along California's coast based on probabilistic estimates of tsunami inundation to help facilitate regional, multi-jurisdictional tsunami preparedness planning.**

- **RECOMMENDATION 14.5 - Develop guidance to assist cities, counties, and special districts (including school,**

water, port and harbor districts) to prepare pre-disaster operational recovery plans for tsunami hazards.

PROBLEM 15 – A successful tsunami hazard mitigation program requires that local officials understand the tsunami threat and have the necessary information to make the right decisions regarding land-use, construction, and emergency management in tsunami-prone areas. Equally important is a knowledgeable public, who will support local programs to mitigate tsunami hazard and will know what to do when a tsunami strikes. This would include informing tourists at local beaches, who may be unfamiliar with tsunami hazard.

- **RECOMMENDATION 15.1 – Incorporate more information on tsunami education and preparedness into the Great California ShakeOut™ program's goals and objectives, the program website, education material, and preparedness activities.** TsunamiReady® awareness should be included as a component of California's fall season ShakeOut™ activities. Community awareness and preparedness for earthquake hazards in California has increased dramatically under the outreach effort and annual ShakeOut™ exercises in which over 9 million Californians have participated. Because earthquakes are the most common cause of tsunamis, tsunami education and outreach could be significantly enhanced by recognizing tsunamis as part of ShakeOut™.

- **RECOMMENDATION 15.2 – Expand California's "Tsunami Preparedness Week" to "Tsunami Preparedness Month."** Research indicates that changes in human behavior are more successfully achieved when a consistent message is delivered from a variety of sources. An expanded preparedness program would provide more time for a more comprehensive program of public education and outreach events, such as school activities, fairs, town hall meetings, evacuation exercises, conducting live code tests of warning systems, and other special events.

- **RECOMMENDATION 15.3 –Develop guidance for private businesses, such as coastal hotels and resorts, to plan, prepare, and implement tsunami awareness measures**. This guidance could include advice for managing guests with no prior tsunami education during an event, promoting tsunami education and preparedness, and distributing materials to hotel and resort emergency coordinators to share with hotel guests. Consideration should be given to offering incentives, such as a reduction in transient occupancy tax, to encourage private sector participation in tsunami preparedness.

- **RECOMMENDATION 15.4 – Encourage property owners and renters located within State-designated**

tsunami hazard zones to obtain coverage from the National Flood Insurance Program (NFIP). Those locations that are outside FEMA high-risk flood zones may be able to gain this additional loss protection through the NFIP at fairly low rates.

Prepare the Maritime Sector for Tsunami Hazards

California has historically focused its tsunami preparedness initiatives on the land-based aspects of coastal communities, and onshore, inland evacuation planning. Less has been done to foster preparedness and response preparations within the maritime sector.

PROBLEM 16 –When a tsunami warning is issued, harbor authorities have very little time to make informed decisions about the relocation and evacuation of vessels, including deciding which vessels and people to send where, and also when to issue the "all clear" for their return. There are a whole host of considerations including: prevailing weather, ocean-going capabilities, length of time to remain evacuated, fuel, food, and distance to alternative ports. Harbor authorities currently lack of reliable information to help make these decisions.

❖ **RECOMMENDATION 16.1 - Form an advisory committee to help prepare and distribute consistent, statewide procedural guidelines for maritime tsunami response & recovery.** The committee should include expertise in emergency management, geology, coastal commission issues, fish and wildlife, military, NOAA, Coast Guard, and local port authorities. The guidelines should include the following overarching standards:

- A single depth contour for offshore evacuations.
- Hazard thresholds defined and addressed for harbor facilities.
- Hazard thresholds defined and addressed for vessels and best practices for ship (re)positioning.
- Protocol recommendations, by type of vessel, for minimum time required for safe evacuation.
- Guidelines for when to issue an "all clear" following a harbor evacuation.
- Procedural guides for harbor dredging and pre-designation of disposal sites for tsunami debris.

❖ **RECOMMENDATION 16.2 - Develop State guidelines for harbor authorities to use in preparing tsunami preparedness, response, and recovery plans for their facilities.** The development effort should include a comprehensive, multi-stakeholder process that includes city/county, Coast Guard, and local private entities that support harbor operations.

❖ **RECOMMENDATION 16.3 - Develop guidelines for harbor authorities to**

establish a State-approved boater safety training program with a tsunami hazard component and procedures for vessel evacuation. Evacuation routes, designated harbor and offshore safety areas, and planning for fuel, food, and other supplies should be addressed in the training.

- **RECOMMENDATION 16.4 - Add a tsunami hazard component to ship pilot licensing programs.** The following topics should be covered: basic tsunami hazard characteristics, flow dynamics in harbors, tsunami warning process and procedures, and pilot preparedness and response training.

PROBLEM 17 – Crescent City Harbor was severely damaged by the 2011 Japanese tsunami. There was an immediate need to dredge the harbor and remove sediment deposited by tsunami currents in the harbor. It took the harbor authority several months to complete federal and State environmental review procedures and acquire the necessary permits to dredge and dispose of dredge spoils. The crab fishing season was affected by the delays in harbor repairs which consequently had a negative impact on the local economy. Such business interruptions can scale-up considerably when much larger shipping and port operations are hampered by harbor restoration and recovery. There is a need to streamline the dredge permitting process to facilitate recovery within a reasonable timeframe and minimize continued financial hardship on the communities who depend on a rapidly repaired facility for their livelihoods.

- **RECOMMENDATION 17.1– Streamline federal, state, and local permitting for disposal of dredge spoils and promote pre-designation of disposal sites to expedite the process in the event of a disaster.** The regulations governing harbor dredging should be amended to facilitate rapid post-tsunami recovery of harbor operations without compromising environmental protection. This includes all federal, state and local ordinances that address removal and deposition of dredge sediment and tsunami debris.

Glossary & Abbreviations

ACOPNE - Academy of Coastal, Ocean, Port & Navigation Engineers

ASCE – American Society of Civil Engineers

ASCE 7 – A document containing recommended seismic provisions for construction of earthquake resilient buildings

BCEGS – ISO Building Code Effectiveness Grading System

Cal OES – California Governor's Office of Emergency Services

California Coastal Act – California law (Public Resources Code Sec. 30000 et seq.) that protects environmentally sensitive areas within designated Coastal Zones

CCC – California Coastal Commission

Cascadia Subduction Zone – An 1100 mile mega-thrust fault zone extending offshore from northern California to British Columbia, along which the Pacific Ocean floor is being driven by tectonic forces beneath the North American continent

CBC – California Building Code

CGS – California Geological Survey

Coastal Zone – A California state-designated zone extending 1000 feet to 5 miles or more inland from the coast that encompasses environmentally sensitive areas

Critical Facility - A structure or other improvement that, because of its function, size, service area, or uniqueness, has the potential to cause serious bodily harm, extensive property damage, or disruption of vital socioeconomic activities if it is destroyed or damaged or if its functionality is impaired

CTPWG – California Tsunami Policy Working Group

Exposure – Potential for being affected by a hazard as a result of close proximity to the hazard (exposure) and vulnerability.

FCC – Federal Communications Commission

FEMA – Federal Emergency Management Agency

Hazard – An event that has adverse consequences, be it personal injury, property or monetary loss, or other undesirable or harmful effects.

Hazard Mitigation Plan – A plan defined by federal law (Public Law 106-390.U.S.) that identifies natural hazards and its potential impact on a community, and must include an approved action plan to mitigate the risk

Hydrodynamic Modeling – Estimating the movement of water throughout a prescribed environment based on fluid mechanics theory

IBC – International Building Code

Live Code Test – Tsunami warning exercise that tests warning systems

Mega Thrust – A fault boundary hundreds of miles long between the earth's tectonic plates along which oceanic crust is forced beneath continental land masses producing great earthquakes

National Tsunami Warning Center – One of two centers administered by NOAA that operate instrumented buoys and tide gauges that measure changes in ocean surface heights and integrates the information with notifications of worldwide seismic events to estimate the wave height and arrival times of tsunamis throughout the Pacific Ocean

NEXT GEN 911 – Initiative to upgrade the emergency 911 call system for text, video, images, and data

NFIP – National Flood Insurance Program

NOAA – National Oceanic and Atmospheric Administration

NTHMP – National Tsunami Hazard Mitigation Program

NWS – National Weather Service

Probabilistic Analysis – Estimating the likelihood of an event (hazard) based on its historical frequency of occurrence (statistics) and knowledge of the physical process (physics) causing the event

Recurrence rate – The number of occurrences of an event per unit time: how often an event occurs

Reverse 911 – An emergency notification system that links a database of telephone and addresses to location via a computer geographic information system

Risk – Potential adverse impact or loss from a natural hazard event usually expressed in terms of magnitude (fiscal, death and injury) and likelihood (probability)

SAFRR – Science Application for Risk Reduction

Seismic Hazards Mapping Act – California law (Public Resources Code Sec. 2690 et seq.) that designates seismic hazard zones of required investigation and improves the resiliency of new construction against seismic hazards

Seiche – a standing wave in an enclosed or partially enclosed body of water, often generated by earthquake shaking or displacement of water by a large mass such as a landslide

ShakeOut™ – A collaboration of many organizations and sponsors to promote earthquake preparedness and safety drills worldwide

TENS – Telephone Emergency Notification System

Tsunami – Japanese word for harbor (tsu)… wave (nami). An ocean wave generated by vertical displacement of the ocean floor caused by earthquake fault rupture or displacement of water caused by a subsea landslide or volcanic eruption

TsunamiReady® - A program administered by NOAA’s National Weather Service that promotes tsunami preparedness by federal, state, local, and tribal governments, and special districts

USGS – United States Geological Survey

WEA – Wireless Emergency Alerts, a joint effort of the wireless industry, the Federal Communications Commission (FCC), and Federal Emergency Management Agency (FEMA) to provide concise messages to WEA-capable mobile devices

End Notes

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