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THE TOHOKU TSUNAMI OF MARCH 11, 2011: A PRELIMINARY REPORT ON EFFECTS TO THE CALIFORNIA COAST and PLANNING IMPLICATIONS

To: Coastal Commissioners and interested parties
From: Lesley Ewing, PE, Sr. Coastal Engineer

This memorandum is intended to provide the Commission with an understanding of tsunami creation, propagation and landfall effects and the implications to coastal California, drawing strongly from the most recent Tohoku tsunami. The discussion includes:

- Tsunami science and detection
- Tsunami warnings and response
- Tsunami damage to the California coast from the Tohoku tsunami

A detailed damage report, variety of reference materials, useful web sites and links are provided at the end of this report.

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EXECUTIVE SUMMARY

The magnitude 9.0 Tohoku Earthquake of March 11, 2011 generated a tsunami that caused damage around the Pacific basin. In California, the major damage occurred from the strong currents that were created as the waves surged in and out of enclosed areas such as ports and harbors. One person drowned in the event and several other people had to be rescued because they underestimated the hazard. Estimates as of early April are that damages are over $48 million statewide, with $12 to $16 million occurring at the Inner Basin of Crescent City Harbor and $25 million at Santa Cruz Harbor. Both Crescent City and Santa Cruz had small oil spills that resulted from sunk or damaged boats. Spills were quickly contained and clean-up efforts have been completed.

A detailed assessment of impacts to the California coast is underway by the California Emergency Management Agency (CalEMA), but four items stand out as "successes" or benefits. There were plans in place; there was time to execute the plans; notifications about the tsunami could be made when most people were still at home; and the peak waves from the tsunami did not happen during high tide.

- **Tsunami preparedness plans were in place**: California tsunami preparedness planning has been a longstanding focus for state and local coastal emergency planners. Two other recent tsunami advisories had also helped prepared emergency planners. When the Tsunami Warning Centers sent out alerts about the Tohoku tsunami, the plans and response efforts were ready.
- **There was time to execute the plans**: There was about a nine hour period between the earthquake off the coast of Japan and when waves would first reach the California coast. Emergency managers used this time to implement tsunami preparedness plans; many low-lying coastal areas were evacuated and many schools in or near the inundation zone were closed for the day. In areas where strong currents were expected, many boat owners took their boats to deep water and harbor staff secured mooring lines and ceased fueling operations. These actions helped keep vulnerable populations from going into the inundation zone and reduce vulnerabilities at marine facilities that cannot move out of the inundation zone.
- **Most people were notified about the tsunami when they were home**: The tsunami arrived in the morning daylight hours, so the warning could reach people through reverse 911, radio, web, and television, before people began traveling to school or work.
- **Tsunami happened during low tide**: The tsunami made landfall along the California coast during low tide and this kept coastal inundation to a minimum. If the earthquake had happened six hours earlier or later, the first tsunami waves would have arrived during high tide and damages would have been far greater.

Much of the tsunami preparedness efforts to date, such as the inundation maps, evacuations signs and sirens, have been for emergency planning and response. The Coastal Commission has considered tsunami risks in some of its permit and Local

Coastal Program decisions, primarily for those in the north coast. While much of the Commission's focus has been with tsunami risk for the north coast, the Tohoku tsunami and last year's tsunami from Chile have shown that most of the State's coastline is at risk from tsunamis. The Commission and staff should be diligent in including tsunami concerns into planning and permitting decisions throughout the state.

INTRODUCTION

Tsunami Generation

Tsunamis are generated when water is displaced by movement of the seafloor or rapid addition of material. There are several different types of tsunamigenic sources (sources for tsunamis). Large magnitude subduction zone earthquakes, where two plates in the ocean push into each other and one moved beneath or above the other, have been some of the most common sources of large tsunamis in recent years.

The 1964 Great Alaskan Earthquake, the 1960 and 2010 Chilean earthquakes, the 2004 Indian Ocean (Sumatra-Andaman) Earthquake and the most recent 2011 Tohoku Earthquake were all subduction zone earthquakes and all created destructive tsunamis.

Submarine landslides, sometimes triggered by earthquakes, are another source of tsunamis. The 1998 Papua New Guinea tsunami was generated by a landslide, and a landslide from Yerba Buena Island, triggered by the 1906 San Francisco Earthquake, created a 5 foot tsunami along the Berkeley shoreline.

Coastal or submarine volcanoes are a third source of tsunamis, and there is geologic evidence that meteor strikes have generated large tsunamis.

The Tohoku Earthquake and Tsunami

The Tohoku Earthquake occurred on March 11, 2011, and ground shaking was first felt on the Japanese mainland at 3:46 PM local time and continued for up to 5 minutes. The earthquake occurred along a subduction zone between the Pacific and North American plates, approximately 81 miles (130 km) offshore on the Oshika Peninsula in northern Japan. A tsunami was generated by the earthquake and damaging waves started washing over the Japanese coast within 15 minutes of the seismic event. Over the ensuing hours, waves reached 1 to 3 miles (3 – 5 km) inland, often extended up to 35 feet (10 meters), and with runup reaching 80 to 100 feet (25 to 30m). Figure 1 shows the inundation zone near Sendai, Miyagi Prefecture.

As of April 4, 2011, the National Police Academy and Japanese Fire and Disaster Management Agency reported: 12,157 fatalities, 15,496 missing, 3,117 injured and 159,828 evacuees; along with 323 fires, and destruction to 2,035 roads, 56 bridges and 36 railroads.

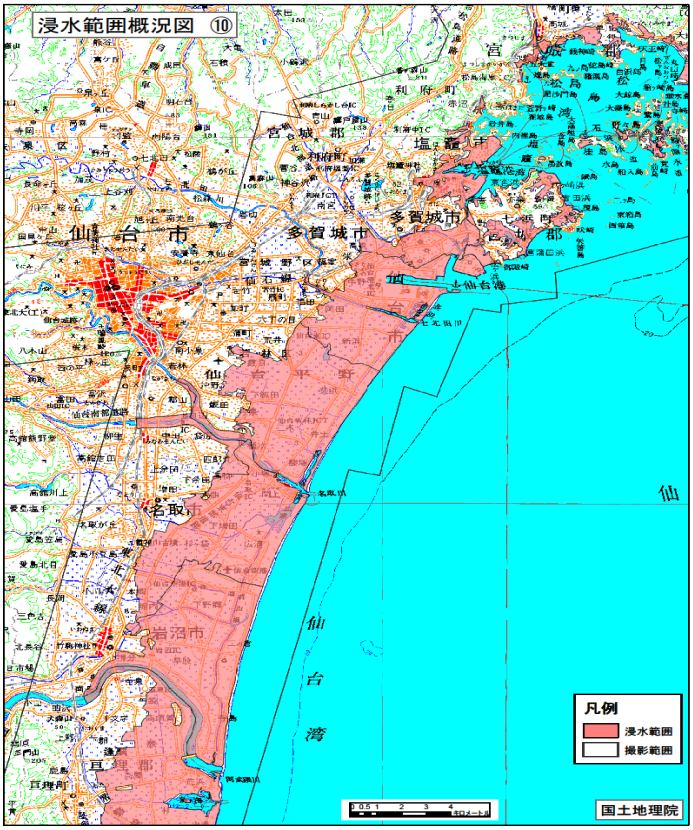


Figure 1: This map shows the inundation area near Sendai, Miyagi. Scale is shown in the bottom of the figure in kms; each small block is one kilometer.

TSUNAMI WARNINGS

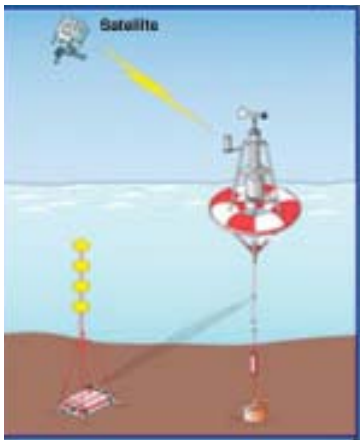
Warning Systems

Tsunami waves travel at speeds comparable to that of a jet plane -- about 475 mph (760 km/hr) in water depths greater than 15,000 feet (4,570 m), slowing in shallow water to about 40 mph (64 km/hr) in water depths of about 100 feet (30 m). Locations such as California that are several thousand miles from the source of the Tohoku tsunami had 9 to 11 hours to prepare for landfall.

During the time that the tsunami was speeding across the Pacific, tsunami hazard identification and warning efforts were underway for the western coast of the US. After detection of the tsunamigenic earthquake event and news of the tsunami damage to the coast of Japan, tsunami scientists and researchers were on the alert. As the waves propagated from the source, they were detected by a network of DART buoys (Deep-Ocean Assessment and Reporting of Tsunamis). Figure 2 shows the configuration of a DART buoy and Figure 3 shows the network of DART buoys that have been deployed around the Pacific.

Tsunamis are very long period waves that cause a barely detectable increase in water level in deep water. Boaters on the open ocean can have a tsunami pass by without knowing it. The minimal height of tsunamis in deepwater has been used as a safety option for boaters and evacuation to deep water is the aquatic equivalent of evacuation to high ground.

Even though tsunami waves in the open ocean do not create large changes in water level, they create a change in water pressure that can be detected by the bottom-mounted pressure sensors in the DART array. Information from the DART buoys is sent to both the West Coast and Alaska Tsunami Warning Center (WCATWC) in Palmer, Alaska, and the Pacific Tsunami Warning Center (PTWC) in Ewa Beach, Hawaii. The WCATWC sends tsunami information and bulletins to California, Oregon, Washington, British Columbia, Alaska, and the US eastern seaboard; the PTWC sends tsunami information and bulletins to Hawaii and all other parts of the Pacific and Indian Oceans. The tsunami warning centers use four tsunami alert levels, in descending order – **warning, advisory, watch and information only**.



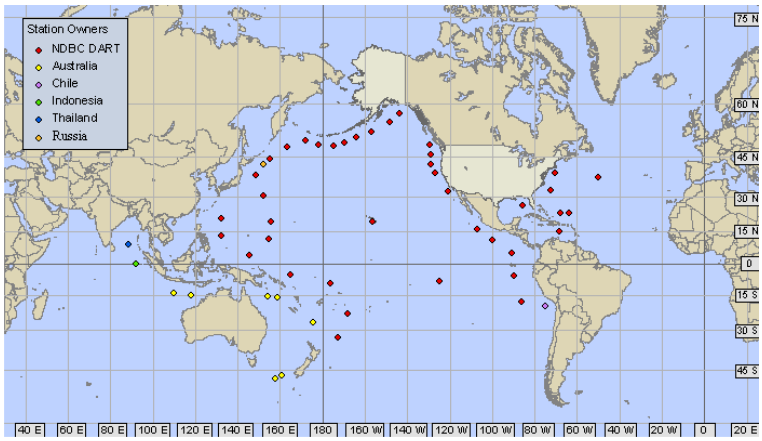


Fig. 2. DART buoy and satellite system; Figure 3. DART network, http://www.ndbc.noaa.gov/dart.shtml

A **tsunami warning** means that a tsunami with significant widespread inundation is imminent or expected, that coastal areas should prepare for flooding, and that wave amplitudes are forecast to be greater than 3.3 feet (1 m). In areas covered by a tsunami warning widespread dangerous coastal flooding and powerful currents are possible and dangers may continue for several hours after the initial wave arrives. Currents may be hazardous to swimmers, boats, and coastal structures and may continue for hours after the initial wave arrival. The warning bulletins that are sent by the Warning Centers may also include likely arrival times of the first wave and the expected maximum wave amplitude[1].

[1] Wave amplitude is the height above normal water level. It is not the crest to trough wave height.

A **tsunami advisory** is issued for areas where extensive inundation is not expected and wave amplitudes are forecast to be between 1 to 3.3 feet (0.3 and 1 m). These areas may experience strong currents that can be dangerous to those in or near the water and as with the tsunami warning areas, strong currents may continue for several hours after the initial wave arrives.

A **tsunami watch** means that all coastal residents in the watch area should prepare for possible evacuation, and as more information becomes available, watch areas will either be upgraded to warning or advisory status, or canceled. An **information only** bulletin is provided to areas that should not expect any damaging or dangerous effects from a tsunami.

After the Tohoku earthquake, DART buoys detected the tsunami within minutes of the earthquake and began sending information to the warning centers via satellite. Both Warning Centers began examining the DART buoy data and issuing regular bulletins concerning the possible generation of a tsunami that would reach the west coast of the US and likely landfall times (times that the first waves would reach various coastal locations). The tsunami warning and advisory were issued through internet bulletins and alerts to tsunami center in CalEMA and to local emergency responders. Within an hour of the Tohoku earthquake there was a **tsunami watch** issued for all of coastal California, as well as Oregon and Washington.

Within three hours of the earthquake, the California coast from the Mexican Border to Point Conception was put into a **tsunami advisory** and the coast from Point Conception north to the Oregon–Washington border was put into a **tsunami warning**. By mid-afternoon on March 11, 2011, the warnings for the California coast had been downgraded to advisories and by the morning of March 12, 2011 all the California advisories were cancelled. Table 1 shows the times for the major decision points for the tsunami alerts in California.

Local Reponses to Tsunami Alerts

In California, the local emergency managers are responsible for determining the local response to the tsunami alerts provided by the WCTWC. The local decisions include whether and when they should issue instructions for evacuations, whether evacuations should be voluntary or mandatory, and when and how to notify coastal residents and visitors.

Every coastal county in California has emergency procedures in place to respond to a tsunami and available notifications techniques vary from one jurisdiction to another, based on community needs, development patterns and existing resources. Some communities, such as Pacifica and parts of Humboldt Bay, have installed sirens along the coast for tsunami alerts. Others, like San Francisco, have sirens with a voice-over option that can be used for a broad range of alerts. Many communities use a reverse 911-phone system for alerts. These organized notification efforts are supplemented by media alerts over radio, television and the internet.

After the WCTWC issued the first bulletin about the Tohoku tsunami, local emergency managers started to implement their response plans. Conference calls were held hourly between federal and state emergency managers and between state and local emergency managers. This close coordination helped provide local authorities with the information they needed to determine appropriate areas for evacuation and emergency personnel were deployed to post signs, assist in evacuation efforts and follow through with the previously developed tsunami response plans. Emergency managers do not always use every available means of notification; for example, while sirens were used in the Humboldt Bay area, the City of Pacifica made the decision to not use its sirens for this recent event.

TABLE 1: KEY DECISION STEPS FOR 2011 TOHOKU TSUNAMI, WITH RESPECT TO CALIFORNIA

DATE*	TIME*	KEY TSUNAMI WARNINGS STEPS
March 10, 2011	9:46 PM	Earthquake offshore from Japan
	9:58 PM	Information Statement, earthquake identified as being Magnitude 7.9; no tsunami warning, watch or advisory in effect for California
	10:59 PM	Tsunami Watch in effect for California and other Pacific coastal areas. Earthquake upgraded to a Magnitude 8.8
March 11, 2011	12:26 AM	Earthquake upgraded to Magnitude 8.9; tsunami watch still in effect
	12:51 AM	Tsunami Warning for coast from Point Conception, CA to Oregon/Washington (OR/WA) border Tsunami Advisory for coast from California/Mexico (CA/MX) border to Point Conception, CA
	2:57 PM	Tsunami warning for Point Conception, CA to OR/WA border downgraded to tsunami advisory Tsunami advisory still in effect for coast from CA/MX to Point Conception
	7:56 PM	Tsunami Advisory zone reduced to coast from Alamitos Bay, CA to Cascadia Head, OR.
	8:54 PM	Tsunami Advisory zone reduced to coast from Alamitos Bay, CA to Douglas/Lane County Border (OR).
March 12, 2011	4:09 AM	Tsunami Advisory zone reduced to coast from Alamitos Bay, CA to California/Oregon Border
	8:10 AM	Tsunami Advisory Cancelled. "Decisions related to reoccupation of coastal zones must be made by local authorities."

* Date and time are provided in local, Pacific Standard Time. Many warnings are provided in UTC or Zulu time and have been converted.

Most people living in central and northern California were made aware of the tsunami by phones, sirens or radio announcements. By the time they awoke on the morning of

March 11, 2011, decisions regarding school closures, road closures and beach evacuations had been made. There has been concern that some of the announcements might not reach the non-English speaking communities; however in the Santa Cruz/Monterey area, regular announcements of the tsunami were posted on Spanish-speaking radio.

There were a number of people who used the notification as a cue to go to the coast to watch the waves, or worse yet, to surf the waves. Many of the people who did go to low-lying coastal areas were on high enough ground that they were safe for this event. Several people were washed into the water by the waves and all but one man were rescued. Except for some isolated incidences, the tsunami announcements were effective in notifying people of the potential danger.

Other Warning Signs of a Tsunami

The Pacific DART system has been effective for warning many people around the Pacific about tele-tsunamis – those tsunamis that travel long distances before hitting the coast. Nature has provided more immediate signs of a tsunami for those in the vicinity of the earthquake. There is first the earthquake itself. Shaking near the coast that lasts longer than 15 seconds is an indication that a tsunami may have been generated. A sudden withdrawal of sea water, or the negative part of the tsunami wave is a second sign. And, often the positive, high water portion of the wave will make loud booming or locomotive type noises as it comes to shore.

These are all signs that a tsunami may be coming to shore and that people should move as quickly as safely possible to a location of high ground. The first wave is often not the largest wave, so people should continue to move to high ground even after the first wave arrives. Furthermore, waves do not always follow a clear progression of getting larger and then smaller through time. The largest wave may be the fourth or fifth wave and may follow a wave or two that seems to have less amplitude than the earlier waves. It can often be difficult to determine when it is clear to return to low-lying ground; however, people should not use the first two or three waves as an indication of the total extent of likely inundation. Attachment 2, Hawaii Tsunami Safety Rules Booklet (Grades 3 through 5) provides more about the warning signs about tsunamis and what to do in case there is a tsunami.

Duration of a Tsunami

A tsunami is often misunderstood to be one enormous wave. However, a tsunami is actually a series of waves or surges of water. The main large waves and high water event may last only 3 or 4 hours, but random large waves are still possible many hours after the start of the tsunami. The highest water level at Crescent City occurred between 2 and 3 AM on March 12, 2011, when the waves coincided with high tide (Personal Communication from Dr. Lori Dengler, Humboldt State University).

The only damage at Ventura harbor – some damage to docks and one person was injured while docking a boat – occurred during high tide when there were strong currents from the tsunami (Personal Communication from Rick Wilson, CGS)

In Santa Barbara Harbor, people had returned to normal water-related activities by the afternoon of the tsunami. Kayakers and board paddlers were in Santa Barbara harbor at 2:29 PM, when the largest wave (3.2 ft/ 0.97 m) to occur in Santa Barbara arrived (Personal Communication from Dr. Jose Borrero, ASR Consultants). The largest wave to reach Santa Monica Bay occurred just six minutes earlier, at 2:23 PM.

The lack of large waves at the beginning of a tsunami event is not always an appropriate or safe indicator of the possible wave heights that can happen later in the event. And, after the tsunami waves have diminished, there can still be rapid rise and fall of water level that can last for several days. For example, water level irregularities were observable in the tidal record as much as two and a half days after the detection of the first waves from the Tohoku tsunami reached the California coast.

Tsunami Planning and Preparedness

California has had several recent reminders of its tsunami vulnerability. In 2010 a magnitude 8.8 subduction zone earthquake in Chile generated a tsunami that damaged boats and docks in southern and central California, with damages to harbor structures estimated at more than $1 million[2]. On November 15, 2006, a magnitude 8.3 subduction zone earthquake near the Kuril Islands generated a tsunami that caused approximately $20 million in damages to the Inner Harbor at Crescent City.

Several decades before these recent events, California started an evaluation of state-wide tsunami rise. One of the events that started this effort occurred in 1960 when, a magnitude 9.5 earthquake in Chile generated a tsunami that was observed all along the California coast. Sixty-one people were killed in Hilo, Hawaii, but no fatalities were recorded in California from this event. Four years later, however, a magnitude 9.2 earthquake off the coast of Alaska generated a tsunami that caused significant damage along the California coast and killed 11 people in Crescent City and 1 person in nearby Klamath. These events prompted the US Army Corps of Engineers to provide plots of the likely wave heights from a 100-year and a 500-year event (i.e. those events with a 1% and a 0.2% probability of occurring each year) for much of the Pacific coast[3]. These were the first major attempts to quantify potential tsunami risks for California's coast.

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[2] Wilson, Rick; Dengler, Lori; Legg, Mark; Long, Kate; and Miller, Kevin (2010) The 2010 Chilean Tsunami on the California Coastline, Seismic Society of America Annual Conference

[3] Houston, James R.; Garcia, Andrew W (1974) Type 16 Flood Insurance Study: Tsunami Predictions for Pacific Coastal Communities. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Garcia, Andrew W.; Houston, James R. (1975) Type 16 Flood Insurance Study: Tsunami Predictions for Monterey and San Francisco Bays and Puget Sound. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Houston, James R.; Garcia, Andrew W. (1978) Type 16 Flood Insurance Study: Tsunami Predictions for the West Coast of the Continental United States. Army Engineer Waterways Experiment Station, Vicksburg, MS.

The growing awareness of the seismic potential of the Cascadia Subduction Zone (offshore from Washington, Oregon and northern California) in the late 1980s and early 1990s generated new or renewed interest in the tsunami risks along the US Pacific Coast. Through support from the NOAA, the Seismic Safety Commission, and the National Tsunami Hazard Mitigation Program, the California Geologic Survey and Cal EMA, the Tsunami Research Center at the University of Southern California developed new inundation maps for sections of the coast with high tsunami exposure or large population centers that could be at risk. The maps were developed for emergency planning purposes and provided what was intended to be the maximum probable inundation zone that an area could experience.

The inundation zones were developed from inundation modeling of numerous possible tsunamigenic sources (local and distant fault ruptures as well as possible submarine landslides). The inundation maps did not specifically include the Tohoku Earthquake as a possible tsunami source. However, the modeling efforts did include a magnitude 8.8 earthquake for the subduction zone off the coast of Japan, so a somewhat similar situation had been considered and included in the map effort.

The Cascadia Subduction Zone, off the coast of Washington State, Oregon and northern California, is the most likely source for large locally-generated tsunami. Geologic evidence has shown that a tsunami generated by the Cascadia Subduction zone could cause extensive inundation of the northern and central coasts of California. The 2009 inundation mapping effort did include the effects from different possible ruptures on segments of the Cascadia Subduction Zone – a full rupture along the subduction zone (magnitude 9.0), a narrow rupture on the south segment (magnitude 8.4), a wide rupture on the south segment (magnitude 8.5) and a rupture on the south segment and the Little Salmon Fault #1 or Fault #2 (magnitude 8.5), so inundation from some large magnitude local source events has been included in the existing maps.

In December 2009, these maps were released for every coastal county and they cover all but the most remote sections of California's coast. Figure 4 shows the inundation map for Santa Cruz; maps for all coastal counties are available for inspection and download at: http://www.conservation.ca.gov/cgs/geologic_hazards/Tsunami/Inundation_Maps/Pages/Statewide_Maps.aspx

At the same time that the emergency planning maps were being prepared, local and county emergency managers throughout the state were working together to develop emergency response plans for tsunamis – determining locations for tsunami warning and evacuation signs, developing safe evacuation routes, acquiring and installing sirens, developing educational materials, and running practice drills. Commission staff has attended annual meetings of the Statewide Tsunami Steering Committee to insure that the planning efforts would be or could be made consistent with the appropriate Local Coastal Programs and with the Coastal Act. And, over the years, the Commission has held two

public workshops on tsunami planning and preparedness, with a focus on what has been happening in California, the first on September 13, 2001 in Eureka, the second on September 15, 2005 also in Eureka (Workshop materials are at: http://www.coastal.ca.gov/energy/tsunami/TsunamiWorkshopAgenda.pdf).
CGS and CalEMA are working now to prepare tsunami hazard maps for both the land-use planning and maritime communities and have been in contact with Commission staff to insure these efforts can be coordinated with LCPs and Commission planning efforts.

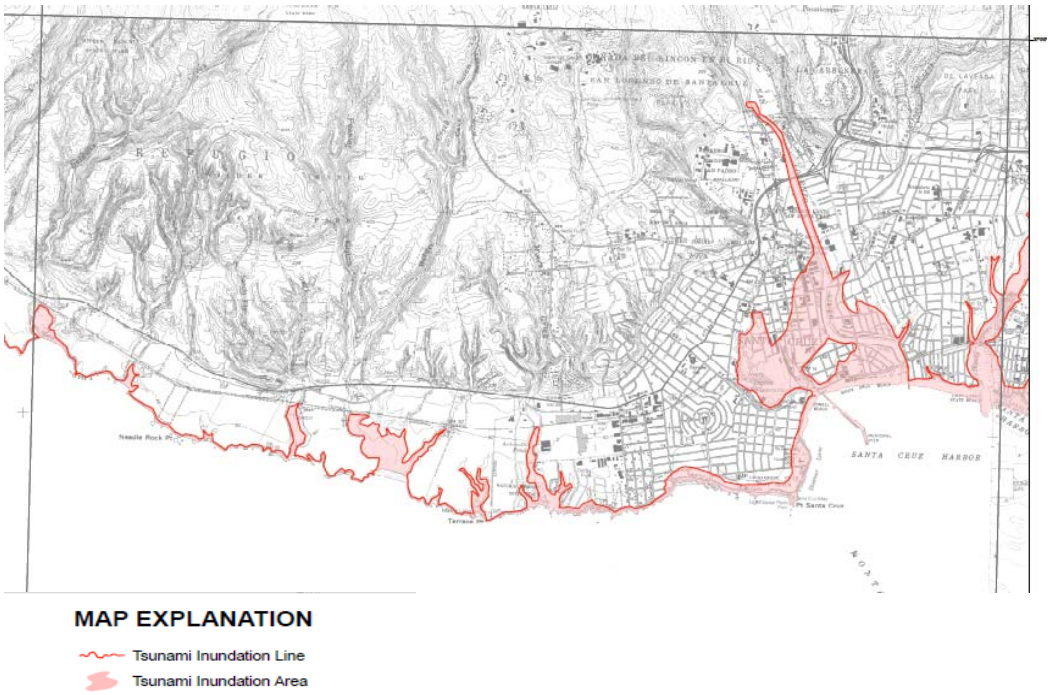


Figure 4: Excerpt of the tsunami inundation map for area near Santa Cruz Harbor. See full map display at http://www.conservation.ca.gov/cgs/geologic_hazards/Tsunami/Inundation_Maps/SantaCruz/Documents/Tsunami_Inundation_SantaCruz_Quad_SantaCruz.pdf for method of preparation, purpose for the maps, tsunamigenic events that were considered in developing the map, disclaimer on use and full reference.

NOAA's TsunamiReady Program

The National Oceanic and Atmospheric Administration (NOAA) has been providing tsunami preparedness tools for many years. Both US tsunami warning centers are NOAA facilities, and NOAA has supported much of the inundation mapping for the state's coastal zone. In 2001, NOAA started a TsunamiReady Program to help community leaders and emergency managers strengthen their local operations. The TsunamiReady Program, developed by the National Weather Service, is designed to help cities, towns, counties, universities and other large sites in coastal areas reduce the potential for disastrous tsunami-related consequences. To date, there are 20 communities in California

that are TsunamiReady[4]. Communities must meet the following criteria o be recognized as TsunamiReady:

- Establish a 24-hour warning point and emergency operations center
- Have more than one way to receive tsunami warnings and to alert the public
- Promote public readiness through community education and the distribution of information
- Develop a formal tsunami plan, which includes holding emergency exercises.
- Comply with the TsunamiReady guidelines (see Attachment 3)

Information on the TsunamiReady Program was also provided at the Commission's 2005 tsunami workshop.

DAMAGES TO THE CALIFORNIA COAST FROM THE TOHOKU TSUNAMI

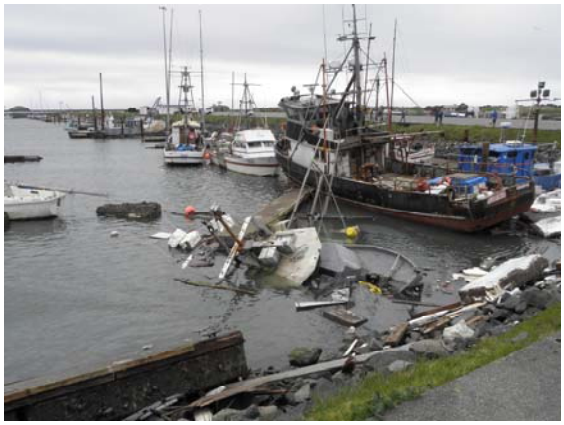
Tsunamis cause many types of damage when they reach the coast. Some of the major aspects of tsunamis are the waves themselves and the resulting flooding. There can be high and damaging wave forces from these waves as is apparent from the many videos of the Indian Ocean tsunami and the Tohoku tsunami that show large areas of destroyed buildings and structures. The large and rapid surge that comes in and out of bays, rivers and harbors create fast current that can scour and undermine foundations, and move around large volumes of sediment.

The majority of damage to the California coast from the March 11, 2011 Tohoku tsunami was from the rapid currents that occurred in enclosed areas, such as ports and harbors. Areas that regularly experience a 5 feet rise and fall of water level over about a 12 hour tide cycle were not able to handle the same change in water level over about 20 minutes. This rapid rise and fall of water in harbor areas created localized eddies and high velocity currents. There were few current meters in place to measure velocities, but eye witness accounts mentioned currents as high as 15 to 20 knots (20 to 23 mph) and in some places, 25 knots (29 mph). These currents scoured around piles and coastal structures, and put large forces on boats and floating docks. Several people who were in low-lying areas had to be rescued when they underestimated the speed and strength of the tsunami. The only fatality in California occurred in Klamath, where a man who was attempting to film the tsunami drowned.

Harbors experienced damage to docks and piers and some of the boats that remained in the harbors and marinas were swamped, capsized, sunk or damaged. Figures 5 and 6 show some of the damage at Crescent City. If mooring lines or dock connections were not strong enough to withstand the currents, boats or pieces of dock would break free and

[4] In alphabetical order, California's TsunamiReady Communities are: Big Lagoon Community and Rancheria Indian Tribe, Crescent City, Dana Point, Half Moon Bay, Huntington Beach, Imperial Beach, Laguna Beach, Newport Beach, Orange County, Orick, Port Hueneme, Redwood National and State Park, Samoa, San Clemente, San Diego, San Francisco County, San Mateo County, Seal Beach, University of California at Santa Barbara, Yurok/Klamath

become floating debris. The floating debris then contributed to the damages as it rammed into boats or docks that had not been damaged by the initial currents.



Figures 5 and 6: Crescent City Harbor, March 12, 2011 after the tsunami.

A few of the boats that sunk in Crescent City and Santa Cruz also caused small, but contained oil spills. Crescent City reported that 6,308 gallons of oily liquid (2,107 gallons of oil) were collected. Large volumes of sediment were relocations within the harbor or carried in from the nearshore to the harbors. Crescent City reported that over 7,500 cubic yards of sediment were deposited in the harbor during the tsunami.

The tsunami damage was confined to areas that are normally wet, such as ports, harbors and rivers. There was no damage to inland areas since there was little, if any, overland flow of water. The high water levels from the tsunami did not coincide with high water levels from tides, and only a few small areas of the coast experienced any flooding from the tsunami. No significant inundation (flooding) damages were observed or reported.

CONCLUSIONS

The March 11, 2011 Tohoku tsunami arrived one week before National Tsunami Awareness Week, March 20 – 26, 2011. Much of the response in California indicated that the coastal population has learned from past tsunamis around the world and they took the tsunami warnings and advisories seriously. Over the past years, the State has worked diligently to develop a range of materials that can help local jurisdictions plan and prepare for tsunamis. These include inundation maps, informational brochures and videos, teaching materials for the science curriculum, warning signs and sirens. Numerous scientific studies, laboratory experiments and computer model runs provide science-based information that is distributed to the public and to emergency managers.

The inundation maps for California have been prepared with model runs of many possible tsunami sources. While they did not include the specific Tohoku earthquake, they did include a possible magnitude 8.8 earthquake on the Japan Subduction Zone as a

source for a distant tsunami. Thus a rather similar event had been considered for the mapping. The Cascadia Subduction Zone, off the coast of Washington State, Oregon and northern California, is the most likely source for large locally-generated tsunami. Geologic evidence has shown that a tsunami generated by the Cascadia Subduction zone can cause extensive inundation of the northern and central coasts of California, and the 2009 Inundation mapping effort did include the effects from three difference ruptures on segments of the Cascadia Subduction Zone – a narrow rupture on the south segment (magnitude 8.4), a wide rupture on the south segment (magnitude 8.5) and a rupture on the south segment and the Little Salmon (magnitude 8.5), so inundation from some large magnitude local source events has been included in the existing maps.

Next steps in this effort will be to provide tools and guidance that are more appropriate for land use planning efforts. Over the years, the Commission has incorporated tsunami risk into the hazards sections of most LCPs and staff will continue to provide the Commission that the best information on coastal hazards for use in all Commission planning and permitting efforts.

Prior to the recent tsunami, CGS and CalEMA began preparing tsunami hazard maps for both the land-use planning and maritime communities. They have been in contact with Commission staff and staff will continue to work with these agencies to insure the land use planning maps can be coordinated with LCPs and other Commission planning efforts. Staff will provide updates on this information to the Commission as it becomes available and incorporate it, as appropriate, into LCPs and permits.

CalEMA is in the process of developing several outreach products for the maritime community. These include:

- A focused effort to model each of California's five major harbors for hazards, including strong currents
- Mapping of offshore safety zones that can be used by boaters who have sufficient time to safely leave port and go to a deep water refuge and working with the harbor districts to identify the vessel classes that can safely use these safe zones.
- Develop statewide guidance on planning and evacuation for the marine community.

CalEMA will work with the Harbor Safety Commissions (upon which the Commission is represented) to develop and disseminate these products.

Immediately following the March 11, 2011 tsunami, CGS initiated surveys of the coastal harbormasters and State Parks personnel to get information on how they learned about the tsunami, what actions they took to prepare for the tsunami, what they observed about the tsunami and what damages or harbor changes occurred. CGS also deployed field teams along the coast to interview harbormasters and park personnel (the questionnaire and initial results are provided in Attachments 4 and 5.) This information will add greatly to our understanding of what happened along the coast on March 11, 2011. It will help provide data for the harbor modeling efforts that will be undertaken and will help prepare better for future tsunamis. Again, Commission staff will work with CGS to

analyze and learn from these surveys and will update the table of damages as new information arises.

Much of the tsunami preparedness efforts to date, such as the inundation maps, evacuations signs and sirens, have been for emergency planning and response. The Commission has considered tsunami risks in some of its permit and Local Coastal Program decisions, primarily for those in the north coast. While much of the Commission's focus has been with tsunami risk for the north coast, the Tohoku tsunami has shown that much of the State's coastline could be at risk from a large tsunami. The Commission and staff should be diligent in including tsunami concerns into planning and permitting decisions throughout the state.

ACKNOWLEDGEMENTS
Much of the damage information presented in this report was obtained from a variety of field surveys undertaken by Commission staff and other coastal scientists in the hours and days following the cancellation of the tsunami advisory. The coverage provided in this memo could not have been possible without input from Jose Borrero, Aggeliki Barberopoulou, Phyllis Grifman, Rick Wilson, Lori Dengler, Mark Legg, Bruce Jaffe, Patrick Lynett, Costas Synolakis, Troy Nicolini, Tom Kendall and Peter Mull; staff such as Jim Baskin, Tamara Gelkin, Bob Merrill, Melissa Kramer, Melanie Faust, Mark Johnsson, and Robin Blanchfield.

REFERENCES AND LINKS TO WEB RESOURCES AND VIDEOS

Commission's 2005 Workshop on Tsunamis:
http://www.coastal.ca.gov/energy/tsunami/TsunamiWorkshopAgenda.pdf

The Tsunami Buoy Network, http://www.ndbc.noaa.gov/dart.shtml

Tsunami Ready Communities: http://www.tsunamiready.noaa.gov/
TsunamiReady Guidelines (also see Attachment 1):
http://www.tsunamiready.noaa.gov/guidelines.htm

California's Tsunami Information Clearinghouse (for the Tohoku tsunami):
http://www.eqclearinghouse.org/CA/category/effect-of-honshu-tsunami-in-ca/

Water levels along the Eastern Pacific, from NOAA tide gauges (note, this is an active site so you must set the plot to start on March 11, 2011 to see the tsunami record.)
http://tidesandcurrents.noaa.gov/tsunami/#

Graphic of wave propagation through the Pacific Ocean, March 11, 2011
http://nctr.pmel.noaa.gov/honshu20110311/20110311Houshu.mov

Video of the Mad River: http://www.youtube.com/watch?v=x8zXor2QBHA

Video of Noyo Harbor: http://latimesblogs.latimes.com/lanow/2011/03/tsunami-docks-ripped-out-in-fort-bragg-fishing-community.html

Video of tsunami in SF Bay: SF Bay:
http://www.sfgate.com/cgi-bin/blogs/inberkeley/detail?entry_id=84822&tsp=1

Video of Santa Cruz Harbor:
http://www.youtube.com/watch_popup?v=1MDnlcbRMaQ&
<https://docim1.consrv.ca.gov/exchweb/bin/redir.asp?URL=http://www.youtube.com/watch_popup?v=1MDnlcbRMaQ%26>

Video of the tsunami coming up Ballona Creek, Marina Del Rey. The bridge is about 1.6 miles (2.5 km) from the ocean. No damage was observed or reported.
http://www.youtube.com/watch?v=bjSncAJdtig&feature=related

Model Forecast for tsunami at Ports of LA/LB
http://web.me.com/jocabo/JAPAN_EARTHQUAKE__MARCH_11,_2011/SOURCE_2_-_SoCal.html

Satellite Images of locations along the Japanese Coast before and after the tsunami:
http://www.abc.net.au/news/events/japan-quake-2011/beforeafter.htm

ATTACHMENT 1: Observations of and Specific Damages to the California Coast

The following summaries provide information on tsunami observations and damage, starting at the north and going south. They are based upon staff observations, observations from local tsunami experts and harbor masters, damage summaries prepared by the Office of Spill Prevention and Response (OSPR) and material from the International Tsunami Information Centre and bulletins issued by the Pacific Tsunami Warning Center and the West Coast/Alaska Tsunami Warning Center. A journal article on damages to the California Coast is in preparation and, if published, a copy will be provided to the Commission.

Several terms are used in the descriptions of damage that may need explanation.

- Wave amplitude is the height of the wave above normal water level. The total water height would include both the tide height, any other factors such as storm surge that could elevate or depress water elevation in addition to the tsunami wave.
- Wave period is the time for both the complete wave crest and trough to pass by a fixed location; often measured as the time between consecutive wave crests.

Del Norte County: Declared a disaster area on March 11, 2011 by the Governor; damages were primarily concentrated in Crescent City area.

Crescent City: Maximum wave amplitude was 8.1 feet (2.5 m) and it arrived at the harbor at 8:56 AM. Eye witness accounts estimated that currents in the harbor were about 20 knots (23 mph). Strong surge was still noticeable more than a day and a half after the first wave arrived in the harbor. The majority of the damage occurred within the Harbor, at the Inner Boat Basin and at Elk Creek. South Beach, south of Crescent City Harbor, had a large amount of Styrofoam debris that, most likely, had been torn from the floating docks in the Inner Harbor by a tsunami wave and carried from the Inner Harbor to the beach by subsequent waves.

Inner Boat Basin

- 16 boats sunk or capsized
- 64 boats damaged
- ~30 boats evacuated to deep water
- All 5 interior docks destroyed; minor damage to all 3 wharf-side dock
- $12 to $16 million in damages from 2011 event
- $20 million in prior damages from 2006 tsunami
- 75,000 cubic yards of sediment deposited in the harbor
- 2,260 cubic yards of debris removed from the harbor
- 6,308 gallons of oily liquid (2,107 gallons of oil) removed.

Several videos have provided clued about the water movement within the inner boat basin. The main current was circulating in a clockwise fashion with many small, but strong, counter eddies. Most of the damaged boats had been pushed to the northeastern

corner of the harbor, and there was a small raft of about 6 or 7 boats in the central portion of the harbor. All the boats that evacuated to deep water survived. 24 of these motored south to Humboldt Bay and all were provided with dock space by the morning of March 12, 2011. Several evacuated boats did not have the fuel to motor 7 or 8 hours to Humboldt Bay and they returned to Crescent City, tied up at A dock (adjacent to the south wharf) and survived the late afternoon and evening surges. By the week of March 21st, wharf space along the southern and eastern wharves had been cleared for crab boats to dock.

There was an oily sheen on the water at the eastern end of the boat basin. OSPR had several trailers on site by March 12, 2011 and by March 18, 2011, 500 feet of sorbent boom and 1,000 feet of containment boom had been deployed at the Inner Harbor. Work was underway to remove petroleum products from sunk or damaged boats and to clear navigation hazards. By April 7, 2011, OSPR and the Harbor District had removed 5,588 gallons of oily liquid (2,007 gallons of oil) from boats and the harbor and had removed and disposed of 1,840 cubic yards of debris. All but four sunken vessels have been either lifted in tact from the bottom or broken into pieces and removed.

NOAA scanned the entrance and channel and no hazardous underwater debris or obstructions were found. There was some damage to the rock slope protection in the harbor and some possible damage to the breakwater. The extent of damage could not be determined until debris was cleared from the edges of the harbor and until an underwater inspection could be performed.

Significant Commission Actions: The most apparent damage in the harbor was to the docks and pilings. Prior to the 2011 event, the 2006 tsunami from the Kuril Islands tsunami had caused approximately $20 million in damages to the docks and some of the pilings. At its February 2011 hearing, the Commission approved a permit to replace the docks and pilings and to add a wave attenuation wall just south of Pier H. The attenuation wall might have reduced the currents and eddies in the Inner Harbor. The new docks and pilings were designed for wave heights in excess of anything in the harbor and for currents slightly higher than to those experienced in the harbor from the Tohoku tsunami. Work was scheduled to begin this spring and, once the harbor is cleared of debris, the new dock and pier work may be able to start, assuming no new work is necessary. At earlier hearings, the Commission had approved permits to do repair and maintenance on the rock slope protection within the larger harbor area and to do repair and maintenance on a section of the breakwater. While the extent of new damage to the rock slope protection and the breakwater is not known, it is possible that the repair work is within the areas already covered by Commission permits.

Elk Creek

Elk Creek was the only location where staff observed tsunami overwash. Debris had been carried out of the creek and deposited on the pedestrian path in Crescent City Cultural Center. One sailboat was grounded at the mouth of Elk Creek.

On the afternoon of March 12, 2011, the Coast Guard attempted to put boom across the mouth of Elk Creek to keep floating debris and pollutants from being carried into the upper reaches of the creek where it could be trapped and be damaging to the creek banks and habitat areas. On March 12, 2011, staff observed three attempts to place boom across the creek; however, at the time, strong surge was cycling in and out of the creek with a 15 to 20 minute period and the workers were not able to hold the boom in place. By March 15, 2011, boom had been placed successfully, but regular adjustments were required for it to remain in place at the creek mouth.

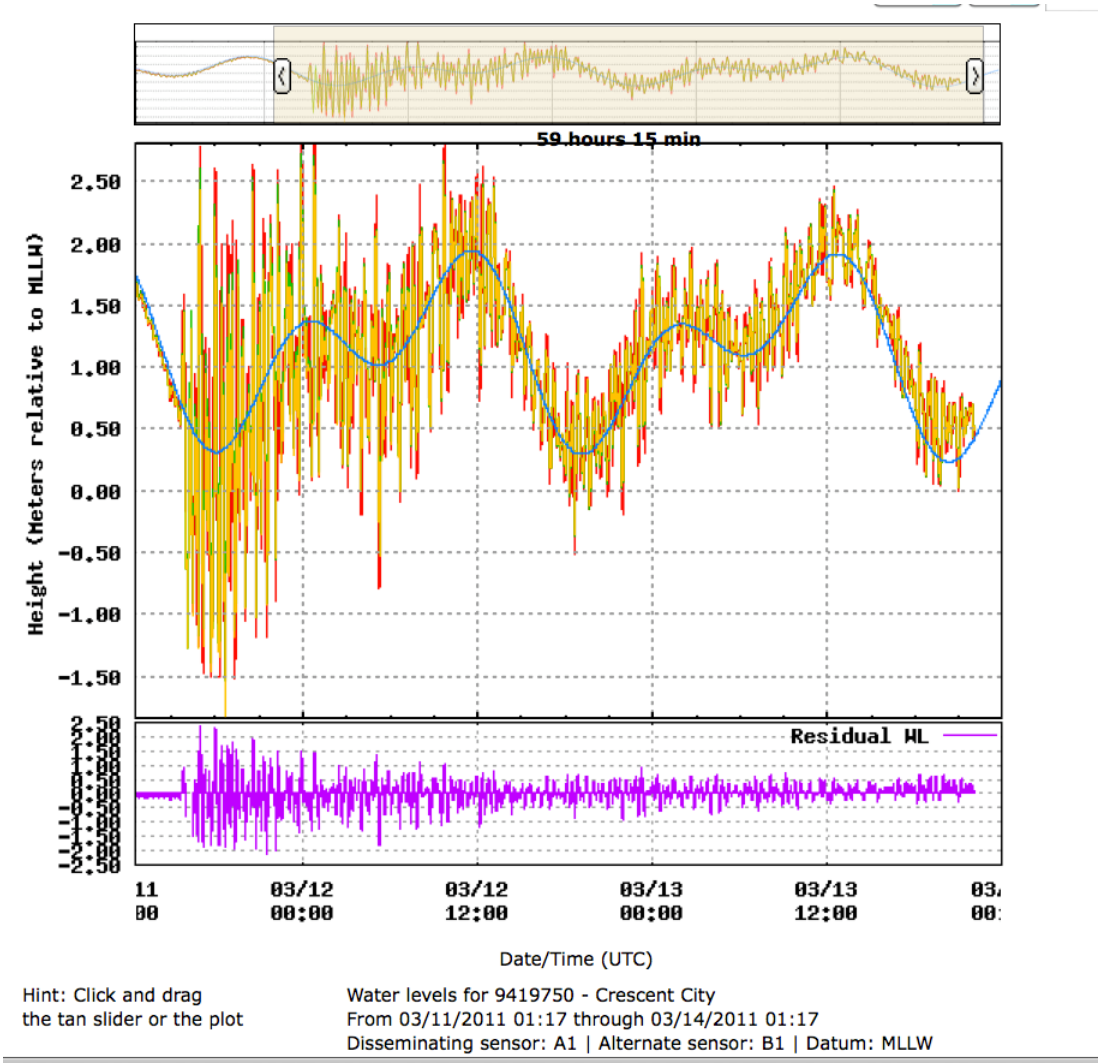


Figure 7: Tide gauge reading for Crescent City at time of tsunami. Solid dark line shows predicted tide and lighter lines show actual tide gauge readings (1, 2 and 6 minute records)
(Screen shot from http://tidesandcurrents.noaa.gov/tsunami/#)

Humboldt County: Declared a disaster area on March 11, 2011 by the Governor; some damage was reported in Humboldt Bay, but, there were no areas of significant damage. Coastal residents were notified about the tsunami by reverse 911 phone calls, and

residents and visitors alike could hear the sirens in the areas near Fields Landing, King Salmon and the PG&E Plant. In some areas, the Fire Department went door to door to provide notification.

Humboldt Bay: Maximum water level change of 61" (5.1 feet, 1.5 meters) was measured at Woodley Island Marina a little before 10 AM on March 11, 2011.

Woodley Island Marina

The harbormaster received news of the tsunami at about 1 AM on March 11, 2011. Harbor staff implemented their tsunami preparedness plan – moved critical files to high ground, checked all the mooring lines for boats docked at the marina and added additional lines when moorings seemed inadequate. There were 15 foot waves breaking over the bar at the entrance to Humboldt Bay so no boats could leave the harbor and get to deep water. All boats in the marina survived the tsunami waves without damage. During the evening and night of March 11 – 12, 2011, the marina was able to provide safe dockage for the 24 boats that evacuated from Crescent City and did not return to home port due to Inner Boat Basin damage.

Significant Commission Actions: The Commission has approved Consistency Determinations for a 5-year dredging effort at the Humboldt Bay bar, entrance channel and navigation channel. Prior to the tsunami, the US Army Corps of Engineers (the Corps) had just finished surveying the bay and the dredge was scheduled to start work on navigation channels on March 14, 2011, and on the bar and entrance channel starting April 1, 2011. Staff from the Corps informed Commission staff that the navigation channel dredging started on March 16, 2011and the bar dredging was still scheduled to start on April 1, 2011; no new surveys were undertaken in support of this work.

Fields Landing

Significant Commission Actions: The fire suppression water line for Fields Landing is buried along the Humboldt Bay shoreline. It has been protected for a number of years by a deteriorating wooden seawall. The tsunami, in conjunction with a large storm that followed immediately after the tsunami, caused accelerated erosion of this section of shoreline and threatened the stability of this water line. The ED issued an emergency permit for rock slope protection along about 350 feet of the shoreline where the water line was most threatened by exposure.

Mad River

Significant Commission Action: After a period of high flow events and observable bank erosion on the Mad River in 2009, Humboldt County Public Works installed emergency bio-groins near the mouth of the river to prevent additional bank erosion. The County has not performed a detailed inspection of these structures; however, the County is not aware of any damage to these structures.

Mendocino County: Declared a disaster area on March 16, 2011 by the Governor; the bulk of the damage in Mendocino County occurred near Fort Bragg and Noyo.

Arena Cove/Point Arena: The maximum wave amplitude was 8.7 feet (2.65 m) and it arrived at 10:34 AM. Point Arena was the first point of landfall for the tsunami, with the first waves arriving at 7:29 AM, the morning of March 11, 2011. The harbor at Arena Cove has a launch ramp and some day anchorages. The harbor does not provide over-night or on-term boat use and there was no indication that any boats were using the harbor at the time of the tsunami. Large surge continued for at least 6 hours, but no damage or flooding was observed.

Significant Commission Actions: Last year, the Commission approved a permit to dredge the anchorage area and Arena Cove and to repair the landward end of the breakwater. There are no reports of damage to these repairs.

Fort Bragg/Noyo

Noyo Mooring Basin

Noyo Harbor is located on the Noyo River, on an outside curve of the river as it heads east. Downsteam of the harbor, the river turns south and then west before going to the ocean. Noyo Harbor provides dock space primarily for fishing boats and the outer harbor has many marine service facilities. Within Noyo Mooring Basin, 51 piles were damaged or uprooted and there was damage to the ends of the three docks closest to the harbor entrance that removed about 12,500 square feet of dock area. There was some damage to the rock slope protection around the harbor and to the debris wall at the harbor entrance. Most of the boats went to deep water before the waves arrived, and as a result, there was no boat damage. There was no information about sedimentation or scour in the channel; however this area rarely requires dredging so sediment deposition is not expected to have been severe. Coast Guard vessels were observed traveling in the harbor on March 13, 2011, so if there had been sedimentation, it was not enough to pose a serious navigation hazard.

Dolphin Isle Marina

Dolphin Isle Marina is a private harbor, upstream of Noyo Mooring Basin and 1 mile from the ocean. Like Noyo Mooring Basin, this marina is built into the river with a long U-shaped series of docks with finger piers providing space for about 150 boats. Between 14 and 22 finger piers were damaged, removing between 28 and 44 slips from service. No boats were damaged; however, the marina hopes to restore slip space in time to service seasonal fishing boats as well as their regular customers. We have no information at this time on needed repair work that is necessary, the construction methods or permit requirements.

San Mateo County: Declared a disaster area on March 11, 2011 by the Governor. County emergency managers sent out voluntary evacuation notices by e-mail and by phone to coastal residents at both 4AM and again at 7 AM. No mandatory evacuation was ordered and the tsunami sirens were not used. In Pacifica, only local residents and the press were allowed within the three block area near the city pier.

Pillar Point Harbor
The Harbor experienced a maximum change in water level of 4.75 feet (1.5 m) and large rotating currents in both the inner and outer harbor areas. Harbor crews worked to check and secure mooring lines for boats and urges boaters to stay away from the harbor. No harbor damage has been reported.

Santa Cruz County: Declared a disaster area on March 11, 2011 by the Governor; the majority of damage in Santa Cruz County occurred at Santa Cruz Harbor.

Santa Cruz Boat Harbor
Early in the morning of March 11, 2011, the harbor officials sealed off the harbor's fuel supply and securing all loose or poorly secured objects. At 5 AM, those who were on the 50 live-aboard boats were told about the tsunami and the harbor was closed to all boaters at 6 AM. The harbor was evacuated at about 11:20 AM; however, based on the video coverage of the harbor during the tsunami, a number of people did come to the harbor area and to the road and railroad bridges over the harbor to watch the tsunami.

Santa Cruz Harbor experienced high water and fast moving currents, starting on the morning of March 11, 2011 and continuing through to the afternoon of March 12, 2011. Water levels were measured for a few hours in the morning by a USGS employee[5] (Figure 8). The plot cannot be used for determining the maximum water level from the tsunami, but clearly shows the surge of water that was coming in and out of the harbor at about 20 minute intervals. The plot also shows that that people should not use the changes in water level from one surge to the next as a way to determine that the tsunami is over, since there is no pattern to the observed pattern to the water levels. There were no measurements of currents; however one eye witness report noted currents up to 8 knots (9 mph) and the tsunami can into the harbor as a rapidly moving surge. The tsunami destroyed "U" dock and seriously damaged five other docks in the inner harbor. The harbor has slips for 827 boats and dry storage for an additional 225 boats and 70 of the slips were damaged. As a result of the tsunami 13 boats were reportedly sunk and approximately 100 more were damaged. There were no fatalities in this area, but, as of the end of March, harbor and boat damage could be well over $25 million.

Monterey County

Monterey Harbor
The maximum wave amplitude at Monterey Harbor was 2.4 feet (0.72 m) and it occurred at 12:13 PM on March 11, 2011. Maximum currents were reported to be about 5 knots and no boat or harbor damage has been reported.

[5] Andy Ritchie was taking measurements from about 10 feet (3m) above the water surface; he was within easy running distance to stairs leading up the bluff, and had established an escape route before starting any measurements.

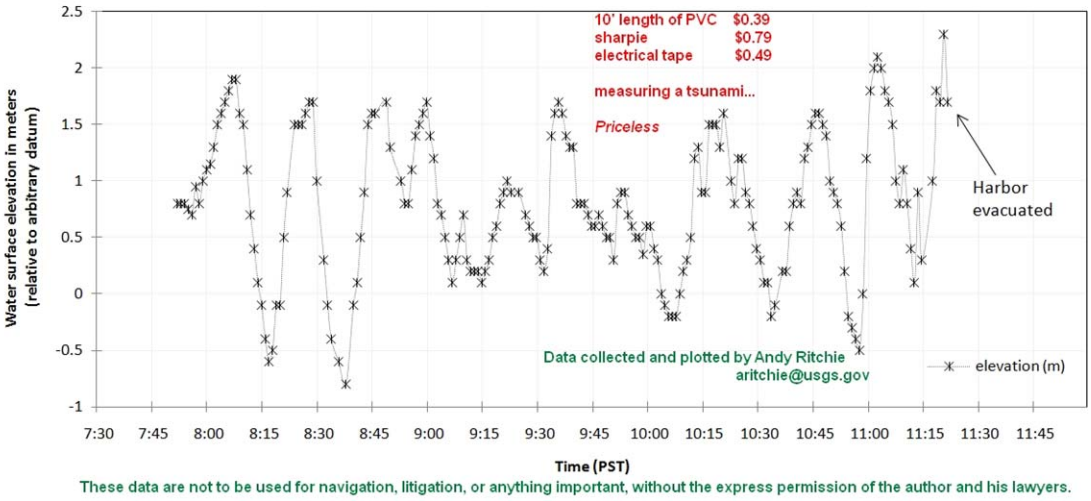


Figure 8: Santa Cruz Harbor Tsunami Amplitude; morning of March 11, 2011
Data and plot courtesy of Andy Ritchie, USGS Pacific Coastal & Marine Science Center, Santa Cruz, CA

San Luis Obispo County: Declared a disaster area on March 16, 2011 by the Governor.

Morro Bay

There were no water measurements at Morro Bay, but eye witness accounts estimate the total change in water level was up to 9 feet (2.7m), and currents were in excess of 10 knots (11.5 mph). Damages were limited to some broken pilings, several boat collisions and one capsized boat. The US Coast Guard surrounded the capsized boat with boom and no oil spill was reports. Beaches were closed during the morning of the tsunami, but were reopened by the afternoon of March 11, 2011.

Port San Luis

The maximum wave amplitude at Port San Luis was 8.6 feet (2.64m) and it occurred at 9:45 AM. The tsunami was observed to look like a rapid cycling of high and low tide. The highest surge, still at low tide, came within inches of overtopping the seawall and flooding the parking area.

Santa Barbara County

Santa Barbara Harbor

Maximum wave amplitude at Santa Barbara Harbor was 3.2 feet (0.97 m) and it occurred at 2:29 PM on March 11, 2011. This was approximately 6 hours after the first tsunami waves made landfall in Santa Barbara and many people were in the harbor when it arrived. The harbor had not been evacuated but people on live-aboard boats had been urged to be cautious; swimmers and surfers were urged to stay out of the water. No boat or harbor damages have been reported.

Ventura County

Port Hueneme, Channel Islands and Ventura Harbors
Water level changes at all three harbors were reported to be about 3 to 4.5 feet (1 to 1.5 m). The highest water occurred early in the morning of March 12, 2011, coincident with high tide. There was some damage to a dock in Ventura Harbor, and a harbor safety officer was injured attempting to help a recreational boater who returned to the harbor when there were still high velocity currents from the tsunami during high tide.

Los Angeles County: Maximum wave amplitude at Santa Monica was 2.8 feet (0.84 m) and it occurred at 2:23 PM on March 11, 2011. The tsunami moved through Ballona Creek as a bore or continuous wave front; video shows that the wave traveled at least 1.6 miles (2.5 km) up the creek channel. Bait barges broke loose from their mooring in Alamitos Bay. The Los Angeles (LA) police department closed city beaches and in El Segundo, Chevron ceased oil transfers at the marine facility and moved its boats to deep water.

LA/Long Beach Harbors
Maximum wave amplitude at LA Harbor was 1.7 feet (0.5m) at 1:15 PM, March 11, 2011. Strong and persistent surge was reported in the ports of Los Angeles and Long Beach. Cargo operations continued throughout the tsunami, but all petroleum transfers were cancelled for the day. The pilot for the fire boat reported that the ladders on the dock opposite the fire boat were being tilted 90 degrees by the currents when he reported to work on the afternoon of March 12, 2011.

Kings Harbor, Redondo Beach
There are no measurements of waves or currents at Kings Harbor, but tsunami-related currents caused damage to several boats.

Catalina Harbor and Twin Harbors, Catalina Island
Strong currents on the order of 10 to 15 knots caused damage to boats and docks.

Orange County: No damages have been reported for the Orange County coast. Tsunami-related currents up to about 10 knots were observed in Dana Point Harbor and up to 4 knots in the Santa Ana River.

San Diego County: Oceanside Harbor had high currents and many small whirlpools. The maximum wave amplitude at La Jolla was 1.4 feet (0.5 m) and it occurred at about noon on March 11, 2011.

San Diego Harbor
The maximum wave amplitude at San Diego Harbor was 1.7 feet (0.5 m) and it occurred at 1:31 PM on March 11, 2011. Currents were estimated to be about 4 knots; one dock was submerged and a boat was sunk near Shelter Island.

ATTACHMENT 2: Hawaii Tsunami Safety Booklet[6]

The Hawaii Tsunami Safety booklet targets grades 3-5, comes with a Teacher's Guide and delivers key tsunami safety information through fun activities and games.

1. All earthquakes do not cause tsunamis, but many do. When you know that an earthquake has occurred, stand by for a tsunami emergency message.

2. An earthquake in your area is one of nature's tsunami warning signals. Do not stay in low-lying coastal areas after a strong earthquake has been felt.

3. Tsunamis are sometimes preceded by a noticeable fall in sea level as the ocean retreats seaward exposing the seafloor. A roar like an oncoming train may sometimes be heard as the tsunami wave rushes toward the shore. These are also nature's tsunami warning signals.

4. A tsunami is not a single wave, but a series of waves that can come ashore for hours. The first wave may not be the largest. Stay out of danger areas.

5. A small tsunami at one point on the shore can be extremely large a few kilometers away. Don't let the modest size of one make you lose respect for all.

6. All warnings to the public must be taken very seriously, even if some are for non-destructive events. The tsunami of May, 1960 killed 61 people in Hilo, Hawaii because some thought it was just another false alarm.

7. All tsunamis are potentially dangerous, even though they may not damage every coastline they strike.

8. Never go down to the shore to watch for a tsunami. When you can see the wave, you are too close to outrun it. Most tsunamis are like flash floods full of debris. Tsunami waves typically do not curl and break, so do not try to surf a tsunami.

9. Sooner or later, tsunamis visit every coastline in the Pacific and all oceans. If you live in a coastal area, be prepared and know nature's tsunami warning signals.

10. During a tsunami emergency, your local civil defense, police, and other emergency organizations will try to save your life. Give them your fullest cooperation

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[6] A link to the booklet on color and to the teacher's manual that will be prepared to accompany this brochure (http://itic.ioc-unesco.org/images/docs/tsunami_safety_rules.pdf), please visit: http://itic.ioc-unesco.org/index.php?option=com_content&view=article&id=1725&Itemid=1347&lang=en

ATTACHMENT 3: TsunamiReady Guidelines
(Excerpted from the TsunamiReady Website -- http://www.tsunamiready.noaa.gov/)

Guidelines for being designated TsunamiReady are given in the following table. Each guideline is fully discussed following the table. The guidelines are based on four population-based categories.

Guidelines	**Population**			
	< 2,500	2,500 - 14,999	15,000 - 40,000	> 40,000
Guideline 1: Communications and Coordination				
Established 24-hour Warning Point (WP)	**X***	**X***	**X**	**X**
Established Emergency Operations Center (EOC)	**X***	**X***	**X**	**X**
Guideline 2: Tsunami Warning Reception				
Number of ways for EOC/WP to receive NWS tsunami messages. (If in range, one *must* be NWR receiver with tone alert; NWR-SAME is preferred)	**3**	**4**	**4**	**4**
Guideline 3: Local Warning Dissemination				
Number of ways EOC/WP can disseminate warnings to public	**1**	**2**	**3**	**4**
NWR - SAME receivers in public facilities	**X**	**X**	**X**	**X**
For county/borough warning points, county/borough communication network that ensures information flow among communities	**X**	**X**	**X**	**X**
Guideline 4: Community Preparedness				
Number of annual tsunami awareness programs	**1**	**2**	**3**	**4**
Designate/establish tsunami shelter/area in safe zone	**X**	**X**	**X**	**X**
Designate tsunami evacuation areas and evacuation routes, and install evacuation route signs	**X**	**X**	**X**	**X**
Provide written, locally specific, tsunami hazard response material to public	**X**	**X**	**X**	**X**

Schools: Encourage tsunami hazard curriculum, practice evacuations (if in hazard zone), and provide safety material to staff and students.	**X**	**X**	**X**	**X**
<u>Guideline 5:</u> Administrative				
Formal tsunami hazard operations plan	**X**	**X**	**X**	**X**
Biennial meeting between emergency manager and NWS	**X**	**X**	**X**	**X**
Visit by NWS official to community at least every other year	**X**	**X**	**X**	**X**

* For cities or towns with less than 15,000 people, a 24-hour warning point and EOC are required; however, another jurisdiction within the county may provide that resource.

Guideline 1: Communications and Coordination Center

A key to effective hazards management is effective communication. This is especially true in tsunami emergencies, since wave arrival times may be measured in just minutes. Such a "short fused" event requires an immediate but careful response. To ensure such a proper response, communities must have set up the following:

1. 24-Hour Warning Point. To receive recognition under the TsunamiReady program, an agency needs to have a 24-hour Warning Point (WP) able to receive NWS Tsunami information and provide local reports and advice. Typically, this might be a law enforcement or fire department dispatching point. For cities or towns without a local dispatching point, a county/borough agency could act for them in that capacity. The warning point needs to have:
    - 24 hour operations
    - Warning reception capability
    - Warning communication/dissemination capability
    - Ability and authority to activate local warning system(s)
2. Emergency Operations Center. Agencies serving jurisdictions of more than 2,500 people will need an emergency operations center (EOC). It must be staffed during tsunami events to execute the warning point's tsunami warning functions. Summarized below are tsunami-related roles of an EOC:
        - Activate based on predetermined guidelines related to NWS tsunami information and/or tsunami events
        - Staffed by emergency management director or designee

- Possess warning reception/dissemination capabilities equal to or better than the warning point
- Ability to communicate with adjacent EOCs/Warning Points C Ability to communicate with local NWS office.

Guideline 2: Tsunami Warning Reception

Warning points and EOCs each need multiple ways to receive NWS Tsunami Warnings. TsunamiReady guidelines to receive NWS warnings in an EOC/WP require a combination of the following, based on population:

- NOAA Weather Radio (NWR) receiver with tone alert. Specific Area Message Encoding (SAME) is preferred. Required for recognition only if within range of transmitter
- NOAA Weather Wire drop: Satellite downlink from NWS.
- Emergency Management Weather Information Network (EMWIN) receiver: Satellite feed and/or VHF radio transmission of NWS products
- Statewide Telecommunications System: Automatic relay of NWS products on statewide emergency management or law enforcement system
- Statewide Warning Fan-out System: State authorized system of passing message throughout warning area
- NOAA Weather Wire via Internet NOAAPort Lite: Provides alarmed warning messages through a dedicated Internet connection
- Direct link to NWS office: For example, amateur or VHF radio
- E-mail from Tsunami Warning Center: Direct e-mail from Warning Center to emergency manager
- Pager Message from Tsunami Warning Center: Page issued from Warning Center directly to EOC/WP
- Radio/TV via Emergency Alert System: Local radio/TV or cable TV
- US Coast Guard Broadcasts: WP/EOC monitoring of USCG marine channels
- National Warning System (NAWAS) drop: FEMA-controlled civil defense hot-line

Guideline 3: Warning Dissemination

1. Upon receipt of NWS tsunami warnings or other reliable information suggesting a Tsunami is imminent, local emergency officials should communicate the threat to as much of the population as possible. Receiving TsunamiReady recognition

requires having one or more of the following means of ensuring timely warning dissemination to citizens (based on population):

- A community program subsidizing the purchase of NWR.
- Outdoor warning sirens
- Television audio/video overrides
- Phone messaging (dial-down) systems
- Other locally-controlled methods, e.g., local broadcast system or emergency vehicle sirens.

2. Once NWS Tsunami Warnings are received, or local information suggests an imminent tsunami threat, the local emergency officials should communicate with as much of the population as possible. To be recognized as TsunamiReady, a community must have NOAA Weather Radio in the following facilities:

Required Locations:

- 24 hour Warning Point
- Emergency Operations Center
- City Hall
- School superintendent office or equivalent

Recommended Locations:

- Courthouses
- Public libraries
- Hospitals
- All schools
- Fairgrounds
- Parks and recreation areas
- Public utilities
- Sports arenas
- Transportation departments
- Nursing Homes/Assisted Living
- Harbors

Receivers with SAME capability are preferred (this is required for recognition only if locations are within range of NWR transmitter). In addition, recognition will be contingent on having one or more of the following means (based on population) of ensuring timely warning dissemination to citizens:

- Cable television audio/video overrides.
- Local Flood warning systems with no single point of failure.
- Other locally-controlled methods like a local broadcast system or sirens on emergency vehicles.
- Outdoor warning sirens.

3. Counties/Boroughs Only: A county/borough-wide communications network ensuring the flow of information among all cities and towns within its borders. This would include provision of a warning point for the smaller towns, and fanning out of the message as required by state policy. Critical public access buildings should be defined by each community's tsunami warning plan.

Guideline 4: Awareness

Public education is vital in preparing citizens to respond properly to Tsunami threats. An educated public is more likely to take steps to receive tsunami warnings, recognize potentially threatening Tsunami events, and respond appropriately to those events. Communities seeking recognition in the TsunamiReady program must:

1. Conduct or sponsor Tsunami awareness programs. Possible locations may include schools, hospitals, fairs, workshops, and community meetings (number of presentations per year is based on population).
2. Define Tsunami evacuation areas and evacuation routes, and install evacuation route signs.
3. Designate a Tsunami shelter/area outside the hazard zone.
4. Provide written Tsunami hazard information to the populace, including:
   - Hazard zone maps
   - Evacuation routes
   - Basic tsunami information

   These instructions can be distributed through mailings, i.e, utility bills, within phone books, and posted at common meeting points such as libraries and public buildings throughout the community.
5. Local schools must meet the following criteria:

- Encourage the inclusion of Tsunami information in primary and secondary school curriculums. NWS will help identify curriculum support material.
- Provide an opportunity biennially for a Tsunami awareness presentation by the local NWS office and/or the local Emergency Manager.
- Schools within the defined hazard zone must have Tsunami evacuation drills at least biennially.
- Written safety material should be provided to all staff and students.
- Have an earthquake plan.

Guideline 5: Administrative

No program can be successful without formal planning and a pro-active administration. To be recognized in the TsunamiReady Program:

1. A Tsunami warning plan must be in place and approved by the local governing body. This plan must address the following:
   - Warning point procedures
   - EOC activation criteria and procedures
   - Warning point and EOC personnel specification
   - Hazard zone map with evacuation routes
   - Procedures for canceling an emergency for those less-than-destructive Tsunamis
   - Criteria and procedures for activation of sirens, cable television override, and/or local systems activation in accordance with state Emergency Alert System (EAS) plans, and warning fan-out procedures, if necessary
   - Annual exercises.
2. Yearly visit/discussion with local NWS Office or Tsunami Warning Center personnel. Due to distance and other logistical constraint in the Alaska and Pacific Regions, this guideline can be met by a visit to the NWS office, phone discussion, or e-mail.

NWS officials will commit to visit recognized communities, at least every other year, to tour EOCs/Warning points and meet with key officials.

ATTACHMENT 4: CGS Emergency Response Questionnaire
(Prepared and distributed by CGS; reproduced in its entirety)

Date: _____ Location: _____ Interviewers: _____

People Interviewed (with contact information):
_____

EMERGENCY RESPONSE QUESTIONS CHECKLIST (**BOLD** portions is most important)

a. How did they first hear about the tsunami? (media, emergency response channels, etc.)
b. Was it clear what actions to take during Warning/Advisory? How did they learn what to do (from the message, from previous event or outreach, etc.)?
c. **What action did they take** (no action, keep people off beach, limited access to dock and boat areas, evacuate people, evacuate vessels out of harbors)? When did they take that action?
d. How did the public respond?
e. When did they end their tsunami response activities and why?
f. (For northern CA) What changes did they make when Warning was degraded to Advisory?

g. Did the event occur like they thought? How did it compare to the Feb. 27, 2010 event?
h. Are there any improvements that the state can make, or suggest to cities, counties, or Warning Center?
i. Do they have any other observations, concerns, questions, or need assistance?

PHYSICAL EVIDENCE (**BOLD** is most important) – checklist, notes, or short answers (tie to maps or photos)

j. Conditions before tsunami (weather, special events, etc.)	
k. Character of tsunami	
i. Form (bore, surge, flood, breaking wave, eddies, etc.)	
ii. Number of surges, timing, which appeared to be the largest?	
iii. Suspended material (mud, sand)	
iv. Color	
l. Inland reach of tsunami flooding	
i. Distance from MSL line	
ii. Elevation	
iii. Locate on map/image	
m. Debris/Sediment movement and deposition (take pictures!)	
i. Type, size, and weight of debris	
ii. Composition and thickness of sediment	
iii. Distance from MSL line	
iv. Highest elevation deposited	
v. Location on map/image	
n. Erosion of beach sands/rip-rap or scour within harbors observed/other geomorphic features	
o. Maximum tsunami amplitudes	
i. Amount	

ii. Where and when observed	
iii. Are there non-NOAA tide gauges?	
p. Maximum tsunami current velocities	
i. Amount (knots, m/s)	
ii. Where and when observed	
iii. Did boats have flow meters?	
q. Damage (take pictures!)	
i. Type (structures, boats, docks, infrastructure, vegetation)	
ii. Severity (minor, moderate, major)	
iii. Cause of damage (surge, buoyancy, drag, eddies, impact)	
iv. Environmental issues (broken pipes, oil spills)	
v. Location	
vi. Estimated cost	
r. Anecdotal information – every location is unique so make sure to capture this information when interviewing people or making observations	

ATTACHMENT 5: Summary of California Coastal Damages (as of April 14, 2011)

This table is modified from a compilation of effects of the March 11, 2011 tsunami along California's coast. This information represents a synthesis of responses from coastal jurisdictions (city and county government, State Parks, and the maritime community) to email questionnaires, in-person surveys and interviews, and video made available by the coastal jurisdictions or the internet. Damage estimates are considered "unofficial" because they have not been verified by CalEMA or FEMA post-event recovery field teams. The citation for this table is:

Wilson, R., Dengler, L., Borrero, J., Synolakis, C., Jaffe, B., Barberopoulou, A., Ewing, L., Legg, M., Ritchie, A., Lynett, P., Admire, A., McCrink, T., Falls, J., Rosinski, A., Treiman, J., Manson, M., Silva, M., Davenport, C., Lancaster, J., Olson, B., Pridmore, C., Real, C., Miller, K., and Goltz, J., 2011, The effects of the Tohoku Tsunami on the California Coast; 2011 Seismological Society of America Annual Meeting, Memphis, TN; poster session.

Location	Maximum Forecast Amplitude (m)	Maximum Measured Amplitude (m)	Maximum Observed Amplitude (m)	Forecast First Arrival Times	Measured/ Observed First Arrival Times	Aprox. Time of Maximum Amplitude	Maximum Current Measured/ Observed (knots)*	Damage	Unofficial damage estimate (UNK=unknown) **
Smith River			1.5-2.0		730	950	15-20	N	
Crescent City Harbor	2.5	2.47	2.7-3.0	723	734	853	20-25	Y	$36,000,000
Klamath River mouth	2.36		2.0-2.5					N	
Trinidad Harbor	1.68							N	
North Spit/Port of Humboldt Bay	1.33	0.97		722	734			N	
King Salmon								N	
Fields Landing								N	
Noyo River Harbor			0.8-1.0			930	15-25	Y	$4,000,000
Dolphin Isle Marina, Noyo River			0.6-0.8				15-20	Y	UNK

Location	Maximum Forecast Amplitude (m)	Maximum Measured Amplitude (m)	Maximum Observed Amplitude (m)	Forecast First Arrival Times	Measured/ Observed First Arrival Times	Aprox. Time of Maximum Amplitude	Maximum Current Measured/ Observed (knots)*	Damage	Unofficial damage estimate (UNK=unknown) **
Albion			0.6-0.8				5-10	N	
Point Arena	1.3	1.74		726	729			N	
Jenner/Russian River			0.6-1.0				4-6	N	
Bodega Bay/Spud Point Marina	0.97		0.5-0.7				8-10	N	
Point Reyes NP	0.63	1.35		739	746			N	
Bolinas/Stinson Beach			0.7-0.9				10-15	N	
Richardson Bay Marina (Sausalito)								N	
Waldo Point Marina (Sausalito)	0.37		1.2-1.5				15-18	Y	UNK
Clipper Yacht Harbor (Sausalito)			0.8					N	
Mare Island		0.07			917			N	
Glen Cove Marina (Vallejo)								N	
Port Chicago (Martinez/Pittsburgh)		0.06			950			N	
Berkeley Marina			0.6				8-9	Y	$125,000
Marina Bay Yacht Harbor (Richmond)		0.35			845	1015-1100	5-6	Y	
Emery Cove Yacht Harbor (Emeryville)			0.4-0.6			1030	4-6	N	
Alameda/Oakland	0.29	0.51			836		4-6	N	
Redwood City		0.12						N	

Location	Maximum Forecast Amplitude (m)	Maximum Measured Amplitude (m)	Maximum Observed Amplitude (m)	Forecast First Arrival Times	Measured/ Observed First Arrival Times	Aprox. Time of Maximum Amplitude	Maximum Current Measured/ Observed (knots)*	Damage	Unofficial damage estimate (UNK=unknown) **
Pier 39 (SF)			0.4-0.6		930			N	
San Francisco Marina	0.73	0.62		808	812	1000	7	Y	
Pacifica	0.85		0.8-1.0					N	
Pillar Point Harbor	0.92		0.7				7-15	Y	UNK
Santa Cruz Harbor	1.01		1.6-1.9			1114	20-25	Y	$23,000,000
Rio Del Mar/Aptos (Santa Cruz Co.)	1.62						5-10	N	
Moss Landing Harbor			2	744	840	1100	15-25	Y	$1,020,000
Monterey Harbor	0.52	0.7	0.7-0.8	744	748		6-7	N	
Morro Bay Harbor	1.18	1.6			800	930-1130	15-20	Y	$500,000
Port San Luis	2.14	2.02		803	810	1152	5	N	
Avila Beach								N	
Oceano Dunes SRA	0.73		0.7-1.0		830	1430		N	
Santa Barbara Harbor	0.48	1.02			829	1600/2400	10-20	Y	$70,000
Ventura Harbor	0.88		1.3		900	115(3/12)	10-15	Y	$150,000
Channel Islands Harbor			0.9-1.2		830	1000	8-10	Y	UNK
Hueneme Naval Harbor								N	
Port Hueneme-Oxnard Harbor District			1.2-1.4		815	1000		N	
Mugu Naval Air Station								N	
City of Malibu	0.35							N	

Location	Maximum Forecast Amplitude (m)	Maximum Measured Amplitude (m)	Maximum Observed Amplitude (m)	Forecast First Arrival Times	Measured/ Observed First Arrival Times	Aprox. Time of Maximum Amplitude	Maximum Current Measured/ Observed (knots)*	Damage	Unofficial damage estimate (UNK=unknown) **
Santa Monica	0.84	0.65			840	1500/2345		N	
Marina Del Rey			0.9-1.0		830	1000	6-8	Y	UNK
Ballona Creek			0.4-0.6				8-10	N	
King Harbor (Redondo Beach)	0.65		0.6-0.7		900	1215	10-15	Y	$15,000
Port of Los Angeles	0.39	0.49		832	840			Y	UNK
Port of Long Beach								Y	UNK
Long Beach Marina-Shoreline			0.6-0.7			1000	8-10	Y	UNK
Long Beach Marina-Alamitos Bay					930	1100		N	
Two Harbors (Catalina)						1330	12-15	Y	UNK
Avalon (Catalina)								N	
Seal Beach Naval Harbor								N	
Orange County State Beaches								N	
Huntington Harbor	0.71				900		8-10	Y	UNK
Santa Ana River (Huntington/Newport)					900		4	N	
Newport Beach Harbor			0.3		846	1530/2230	5	N	
Laguna Beach	0.6							N	
Dana Point Harbor			0.6		830	1630	10-15	Y	UNK

Location	Maximum Forecast Amplitude (m)	Maximum Measured Amplitude (m)	Maximum Observed Amplitude (m)	Forecast First Arrival Times	Measured/ Observed First Arrival Times	Aprox. Time of Maximum Amplitude	Maximum Current Measured/ Observed (knots)*	Damage	Unofficial damage estimate (UNK=unknown) **
Oceanside Harbor			0.5		900		4-6	N	
Carlsbad			0.6		915			N	
Encinitas/Batiquitos and San Elijo Lagoons			1					N	
Del Mar	0.53		0.9					N	
La Jolla	0.7	0.39	0.9	814	847			N	
Scripps		0.25	0.2		850	1115		N	
Mission Bay - Quivera Basin/Lifeguard HQ					900	1630	5	Y	$800
Mission Bay - Quivera Basin/Seaforth Marina						1530	6-8	Y	$136,000
Ocean Beach			1			1530		N	
Point Loma Submarine Base/Ballast Point	0.69		0.5					N	
Point Loma Sport Fishing Docks/Marina								N	
Shelter Island-South Harbor Police Dock			0.8			1615	12-15	Y	$110,000
Shelter Island-South/Shelter Island Marina								N	
Shelter Cove Marina (Bali Kai)			0.3			915, 1115	7-8	N	
Harbor Island West Marina			0.3			1500-1600	10-15	Y	UNK

Location	Maximum Forecast Amplitude (m)	Maximum Measured Amplitude (m)	Maximum Observed Amplitude (m)	Forecast First Arrival Times	Measured/ Observed First Arrival Times	Aprox. Time of Maximum Amplitude	Maximum Current Measured/ Observed (knots)*	Damage	Unofficial damage estimate (UNK=unknown) **
Mariott Marina - San Diego			0.6			1600-1630		N	
Southwestern Yacht Club Marina								N	
Port of San Diego	0.35	0.63	0.4			1615		N	
Half Moon Marina (SD)			0.6-0.9			1630	3-4	N	
San Diego Naval Station/Base			0.3					N	
Chula Vista Marina-CA Yacht Marina			0.2					N	
Naval Air Base (Coronado)			0.3					N	
Coronado Island Lifeguard HQ			0.6			1500		N	
Silver Strand State Beach			0.3-0.6		930	1000		N	
Imperial Beach	0.78		0.5					N	
Tijuana River Wetlands		0.2			930	1315		N	

*** Velocity estimates were gathered from eyewitness accounts and preliminary video evaluations, and therefore may be overestimated.**

**** Unofficial damage estimates represent what local officials have provided and may not match what the official estimates come out of CalEMA and FEMA**