Guidelines and Best Practices for Tsunami Hazard Analysis, Planning, and Preparedness for Maritime Communities

Developed by United States National Tsunami Hazard Mitigation Program (US NTHMP) Mapping and Modeling Subcommittee, Mitigation and Education Subcommittee, and Warning Coordination Subcommittee

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Purpose of Maritime Planning and Preparedness Guidelines

The purpose of the guidelines presented here is to address the minimum requirements to develop consistent and reliable tsunami preparedness products for maritime communities; those communities with commerce and/or population infrastructure having either a reliance on waterways or that are in close proximity to water. Recent tsunamis, including the 2011 Japan Tohoku-Oki event, have caused greater than $100M in damage to U.S. ports and harbors around the Pacific Ocean. Currently, there is no consistent approach to analyze, plan, prepare, and mitigate tsunami hazards for maritime communities. This has led to confusion amongst the public and incorrect assumptions about the tsunami threat that translate into potentially ill-advised actions taken by harbors and boaters. NTHMP-funded agencies producing tsunami hazard products and maps are expected to adopt these guidelines. For consistency, and in order to minimize public confusion, all other organizations doing similar work are also strongly encouraged to adopt these guidelines.

Intended Audience

These guidelines and best practices are intended for government and non-government entities responsible for emergency response planning and overall safety of harbors/ports; this group is referred to as the "maritime community." These entities may include:

- Federal Government– NOAA, Coast Guard, other military/Dept. of Defense, US Army Corp of Engineers, U.S. Geological Survey, Federal Emergency Management Agency
- State Government – emergency services, geological surveys, boating/waterways
- Local Government – emergency management, police/fire, lifeguard, park rangers
- Academic – researchers, engineering, modeling
- Non-government[1] – harbor masters, port captains, harbor patrol

It is essential that local emergency managers and maritime communities work closely together to produce accurate and seamless tsunami response plans. We recommend that states and territories form "Maritime Advisory Committees" or Work Groups to help guide product development and implementation of these products. All planning should be coordinated with state tsunami programs and local emergency managers responsible for on-land tsunami evacuations. Though these guidelines apply to partners who receive NTHMP funding, they are also recommended for use by other organizations looking for direction in producing similar products.

Essential Guidance for NTHMP Funded Entities:

1. Entities planning to create local maritime guidance should consult with the maritime communities to: a) share examples of products which can be produced for tsunami planning; b) determine what response capabilities the maritime communities have; and c) match the products to their needs and capabilities.
2. All numerical models used should be verified, meet benchmark criteria, and must follow the acceptance process developed by the NTHMP Mapping and Modeling Subcommittee.
3. Modelers should use source parameters which appropriately capture the tsunami hazard for planning, and should use high-resolution digital elevation models that accurately represent the solid, permanent structures within the harbor\port of interest.
4. All products should be accompanied by detailed explanations of their purpose, limitations, and how they were produced.
5. Planning tools should be straightforward for use by maritime authorities, but should also allow for response to tsunamis of different sizes, especially those with Advisory and Warning alert levels. These tools should also include an evacuation plan for when an alert is not given.
6. Maritime communities should be encouraged to consistently exercise their tsunami response activities on a regular basis.

[1] In American Samoa, the harbor masters, port captains fall under Local Government, and the Non-government category includes commercial/private boat owners.

Objective and Scope of the Guidelines are**:**

- To promote accurate and consistent tsunami hazard mitigation products in order to provide information upon which users (emergency managers, harbor masters, citizens, etc.) may base their actions;
- To depict the area(s) affected by and safe from a tsunami;
- To create viable maps through a thorough assessment of local risks;
- To facilitate and encourage coordinated emergency management, overall maritime, and individual harbor response planning activities.

The guidelines are divided into several sections based on the needs of the product developers and users. The three NTHMP subcommittees, Mapping and Modeling (MMS), Warning Coordination (WCS), and Mitigation and Education (MES) are responsible for developing and monitoring the use of the following:

- **Guidance for tsunami hazard analysis, modeling, and mapping (MMS)**
- **Guidance for tsunami response, preparedness, and education (MMS, MES and WCS)**
- **Guidance for tsunami mitigation and recovery (MMS and MES)**

The following section discusses the first of these three guidance documents. It covers aspects of tsunami hazard analysis, and associated modeling and mapping products that demonstrate the tsunami threat for maritime communities. This document also address some aspects of tsunami response and preparedness as they relate to specific hazard analysis products.

Part 1: Guidance for Tsunami Hazard Analysis, Modeling, and Mapping

The foundation for these guidelines are related to outcomes from the 2012, 2013, and 2014 NTHMP Summer Tsunami Workshops, portions of which were presented at the Fall 2013 American Geophysical Union in San Francisco (Wilson and Eble, 2013). The guidelines also address the elements of maritime tsunami planning established in the 2013-2017 NTHMP Strategic Plan.

These guidelines have been developed based on the tsunami response and planning experience of various maritime communities, and the results of detailed tsunami hazard analysis by government and academic institutions. Demonstration projects have provided valuable analyses and practical solutions. Where appropriate, these demonstration projects are referenced in the guidance.

In order to determine the appropriate tsunami mapping products and guidance for use by maritime communities, the tsunami hazards and potential types of damage that can occur should be understood to the extent possible. The following are examples of tsunami hazards and potential damage related to those hazards:

- Sudden and significant water-level fluctuations
  - Boats and docks could hit bottom (grounded) as water level drops
  - Docks and boats could overtop piles as water level rises
- Strong and unpredictable currents, especially where there are narrow passages, channels or harbor openings, underwater glacial moraines, or other natural or man-made structures that form constrictions
- Tsunami induced bores, seiches, and amplified waves resulting in swamping of boats and damage to docks
- Eddies/whirlpools causing boats to lose control
- Drag on deep draught boats causing damaging forces to the docks they are moored to
- Collision with other boats, docks, floating ice and/or debris in the water
- Long duration of dangerous tsunami conditions which may potentially last tens of hours after first wave arrival, causing problems for inexperienced and unprepared boaters who may try to move their boats within harbors or take their boats offshore during a tsunami
- Sediment movement from both erosion and deposition which can create hazards to navigation
- Environmental issues with debris and contaminants in the water which can slow recovery processes

In addition to providing guidance for products addressing various tsunami hazards, NTHMP representatives provide examples of how these products can be integrated into response and mitigation planning documents. These planning documents are essential for helping maritime communities assess the hazard for their harbor and develop appropriate response/mitigation activities for their constituencies.

1.1 Use of Numerical Tsunami Models and Digital Elevation Models/Grids

All entities receiving funding from the NTHMP should demonstrate the validity/accuracy of the numerical model used for maritime guidance efforts. For maritime work, the accuracy of numerical modeling of tsunami currents should be first verified prior to use of a particular model.

During the 2011 NTHMP Model Benchmarking Workshop, a suite of numerical models was verified and benchmarked for use to determine tsunami inundation and run-up (NOAA, 2012). In 2015, a currents benchmarking workshop similar in process to that of the 2011 workshop was held to address the adequacy of tsunami models to capture current velocities. This was accomplished by comparing model results to real tsunami velocity data from controlled wave-tank experiments, ADCP data, and video interpretation (NOAA, in press). Results from the 2015 workshop are still under evaluation. Preliminary findings imply that most models proposed for use by NOAA and NTHMP members are similar in their ability to identify areas of high currents, especially where jetting and eddies occur. A few models that participated in the workshop consistently captured velocities with a greater degree of accuracy than others, especially where eddy migration occurred in data sets. In the event these preliminary findings hold, the deficiencies of the models in the areas where eddies form and are expected to migrate might be addressed by: 1) running multiple models and combining the results to capture the maximum current velocities; 2) binning modeled current velocities into numerical categories related to damage potential, to reduce the reliance on absolute accuracy of the velocities; and/or, 3) identifying and encircling the areas where eddies are expected to be generated and migrate. These three options will be addressed in more detail in later sections and also might be revised when results from the 2015 workshop be fully analyzed.

High-resolution digital elevation models (DEMs) should be used in numerical modeling to adequately capture maritime structures and other important features within harbors and ports.

Lynett and others (2013) demonstrated that the relative accuracy of DEMs starts to converge between 10m and 30m resolution. Therefore, the NTHMP recommends using DEMs of at least 10m resolution to capture details within harbors and ports, if such 10m resolution DEMs are available. If models rely on coarser than 10m resolution DEMs, modelers are expected to verify that modeling results has converged at the coarser resolution using the benchmark problems.

DEMs should be constructed using the best available bathymetric and topographic elevation data at the time of development and should then be evaluated by local experts familiar with the region of interest. For most areas of the U.S. coast, the National Center for Environmental Information (formerly National Geophysical Data Center) has produced bathymetric-topographic DEMs at 10m resolution specifically for use by numerical tsunami models. Recent, high resolution (1m to 2m) LiDAR data have been collected in many coastal areas and, once processed and available, these data should be used to update the topography of existing DEMs.

1.2 Maritime Tsunami Hazard Preparedness Products

The products may include maps and plans that are printed, digital files, or are interactive/web-based. Specific tsunami hazard mapping products that are likely most useful to maritime communities are:

- **Identification of areas of past tsunami damage and strong currents**
- **Mapping current velocities and relationship to damage**
- **Identification of areas of potentially large water fluctuations**
- **Identification of areas of potential bores, seiches, or amplified waves**
- **Identification of timeframe for damaging currents**
- **Identification of safe minimum offshore depth**

Discussion of these products follows and will be the focus of the modeling and mapping portion of the guidance. Guidance will be provided for both the "development" and "use" of each of these products. Where appropriate, hazard product developers should reference and utilize the general map instructions at the end of this section of the guidance unless it conflicts with specific guidance for each tsunami hazard product. Movies showing the current velocities could provide a visualization of hazard analyses and educate harbor personnel as well as the public about the impacts of these hazards.

Product 1: Identification of Areas of Past Damage and Strong Currents

Historical documents, personal accounts, and videos from past tsunamis should be researched to determine if, where, and how much damage occurred in a specific maritime community during past tsunamis. The NOAA-National Center for Environmental Information historical tsunami database is the most comprehensive data source and should be a starting point for information and other references. Newspapers and private photo collections might also be sources for information. For more recent or modern tsunamis, current velocity instruments (e.g. Acoustic Doppler Current Profiler – ADCP), online and security camera videos, and interviews with harbor personnel may provide the most accurate information; keep in mind that although the general public may provide personal accounts of tsunami currents and damage, experience has shown that these accounts may be exaggerated or inaccurate due to their lack of experience in making such observations. In addition to noting areas of damage, collect information on where strong currents and sediment movement were observed as well as areas where strong currents seemed absent.

Guidance:

Once sufficient information is obtained, create a database and possibly maps showing the areas impacted by past tsunamis. For example, Wilson and others (2012a) developed maps showing where strong and erosional currents had developed in Santa Cruz Harbor during the March 11, 2011 Tohoku-Oki tsunami (Figure 1). Table 1 also demonstrates how historical tsunami information, especially in maritime communities, can be summarized. Historical information will help members of maritime communities understand the severity of past tsunamis for future reference. If there is sufficient details, the historical database should also include information on how and where the damage occurred. This information can be used to not only develop tsunami response scenario “playbooks” for a particular harbor they can also help validate numerical models of tsunami currents and damage; an example of a tsunami response playbook is provided as Appendix B.

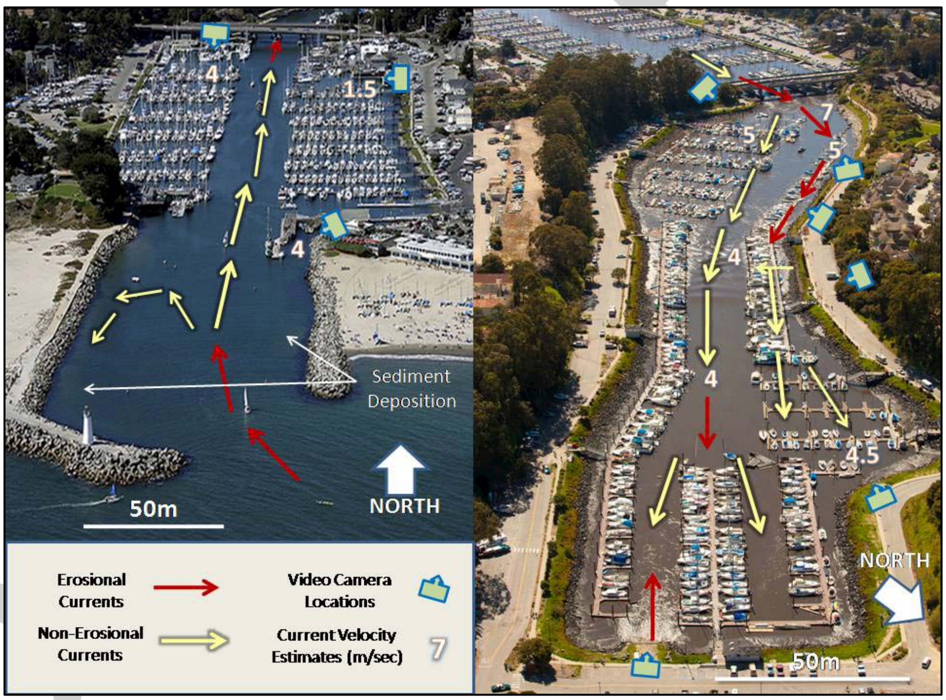

Figure 1 Location of strong and erosional currents inside Santa Cruz Harbor during the 2011 Japan tsunami (from Wilson and others, 2012a).

Table 1 Example of table showing impacts from historical tsunami events in Santa Cruz County (from Maritime Tsunami Response Playbook for Santa Cruz Harbor, 2014).

Notable Historical Tsunamis in Santa Cruz County

- Run-up amplitude, in feet, above normal tide conditions

- Distant Source - Tsunamis without felt earthquakes

- Local Source - Earthquake and tsunami together

NDR = no specific reports of effects or damage

THE NATIONAL TSUNAMI HAZARD MITIGATION PROGRAM (U.S.)

Date	Magnitude-Source area	Tsunami location	Run-Up/Amp	Remarks
1/16/1840	M6.3? (storm)	Santa Cruz	?	flooding 200 yds inland
10/8/1865	M6.5 - San Andreas Fault	Santa Cruz	?	"...tide rose and fell with convulsive throbs..."
		Soquel	?	"...(ocean) very rough and cross cutting..."
10/21/1968	M6.8 - Hayward Fault	Santa Cruz	?	"...(San Lorenzo River) commenced rushing upstream..."
5/10/1877	M8.3 - Chile	Santa Cruz	4-5 ft	no damage reported
6/15/1896	M8.5 - Japan	Santa Cruz	4-5 ft	destroyed protective dike; damage to ship
11/11/1922	M8.5 - Chile	Santa Cruz	?	strong currents; no damage
2/3/1923	M8.5 - Kamchatka	Santa Cruz	?	strong currents; no damage
4/1/1946	M8.8 – Aleutian Islands	Santa Cruz	10 ft	One drowning; some damage
11/4/1952	M9.0 - Kamchatka	Santa Cruz	?	boat damage; "...(swells) running for several days..."
5/22/1960	M9.5 - Chile	Santa Cruz	3 ft	flooding up to base of boardwalk
		Capitola	?	flooding over seawall
3/28/1964	M9.2 – Alaska	Santa Cruz	10 ft	boats sunk leaving harbor; $100k in damage to boats, infrastucture
		Capitola	6 ft	flooding over Esplanade seawall
		Rio Del Mar	?	dramatic tidal changes
2/4/1965	M8.2 - Aleutians	Santa Cruz	2 ft	no damage reported
10/18/1989	M6.9 – Loma Prieta	Santa Cruz	1 ft	minor dock damage from tidal fluctuations
9/29/2009	M8.0 – Samoa	Santa Cruz	1-2 ft	strong currents; no damage
2/27/2010	M8.8 – Chile	Santa Cruz	2-3 ft	minor damage in harbor; strong currents
3/11/2011	M9.0 - Japan	Santa Cruz	5-6 ft	significant damage in harbor; $22M in damage

Product 2: Mapping Current Velocities and Relationship to Damage

Much of the tsunami damage that occurs inside harbors can be directly attributed to strong currents. Maps identifying areas of strong tsunami currents as well as areas where little or no currents are likely to exist can be a useful tool for harbor response and mitigation planning. Although maps showing historical tsunami information are helpful, tsunami currents from numerical modeling of historical or scenario tsunami events will be more useful for planning purpose by harbors.

As previously noted, there are potential limitations to models regarding accuracy as well as adequately capturing areas where eddies form and subsequently move away from the generating area. Therefore, additional precautionary steps should be taken to ensure that areas where dangerous tsunami currents may occur are correctly identified. In addition, it is recommended that products for tsunami planning be as simple as possible to understand and use.

Guidance:

Once a numerical model is verified as being adequate[2] for use, the following guidance for modeling and resulting map production should be followed:

[2] To improve identifying areas of potentially dangerous currents, modelers may consider an ensemble modeling approach; one in which multiple verified models are run and then the maximum value at each pixel/grid from the

1) Select a suite of historic events and synthetic tsunami scenarios as model input. These scenarios should represent various events that would trigger Advisory-level alerts and small, medium, and large Warning-level alerts. The considered scenarios can be utilized for planning harbor response for future events. Ideally, it would be helpful to model scenarios that can identify the threshold where damage starts to occur and where in-harbor actions are necessary.
2) Use DEMs with a minimum grid resolution that captures all important solid, permanent structures within the harbor/port which could influence currents. DEMs should incorporate recent bathymetric data that represents the average depths considering dredging activities. Make sure that structures that allow for water movements beneath (wharfs, docks, piers) are not solid features in the DEMs.
3) Save the time-history of the numerical modeling output results for all runs. This information can be used for production of other tsunami hazard products discussed in this guidance. Once the currents are modeled accurately, current velocity maps or derivative maps relating currents to damage can be produced.

Lynett *et al.* (2013) determined that damage in harbors might vary based on the age and location of docks and boats yet noted some generalities about the relationship between tsunami currents and damage. One such generality, as shown in Figure 2, is a general trend of increasing damage with increasing current speed. In these data, there is a noticeable threshold for damage initiation at ~3 knots [1.5 m/s]. When 3 knots is exceeded, the predicted damage level switches from a no-damage to minor-to-moderate damage category. Thus, in the simulated data, 3 knots represents the first important current velocity boundary. The second threshold is at 6 knots [3 m/s], where damage transitions from moderate to the major category. A third current speed threshold is less clear, but is logically around 9 knots [4.5 m/s], where damage levels move to the extreme damage category. Additional damage observations with correlated current predictions are needed to better define this threshold. More recent data indicate that although the 3-6-9 knot thresholds work for newer (<30-40 years old) and well-maintained docks and harbor infrastructure, velocity thresholds of 2-5-7 knots might be more appropriate damage thresholds for older (>40-50 years old) and less maintained docks (Pat Lynett, personal communication).

multiple runs is selected. In selecting specific models, a modeler is encouraged to include as part of their ensemble modeling, a high-order or 3-D model to verify results.

Damage Index:	Damage Type:
5	Complete destruction
4	Major dock/boat damage, large vessels off moorings
3	Moderate dock/boat damage, mid-sized vessels off moorings
2	1-2 docks/small boats damaged, large buoys moved
1	Small buoys moved
0	No damage

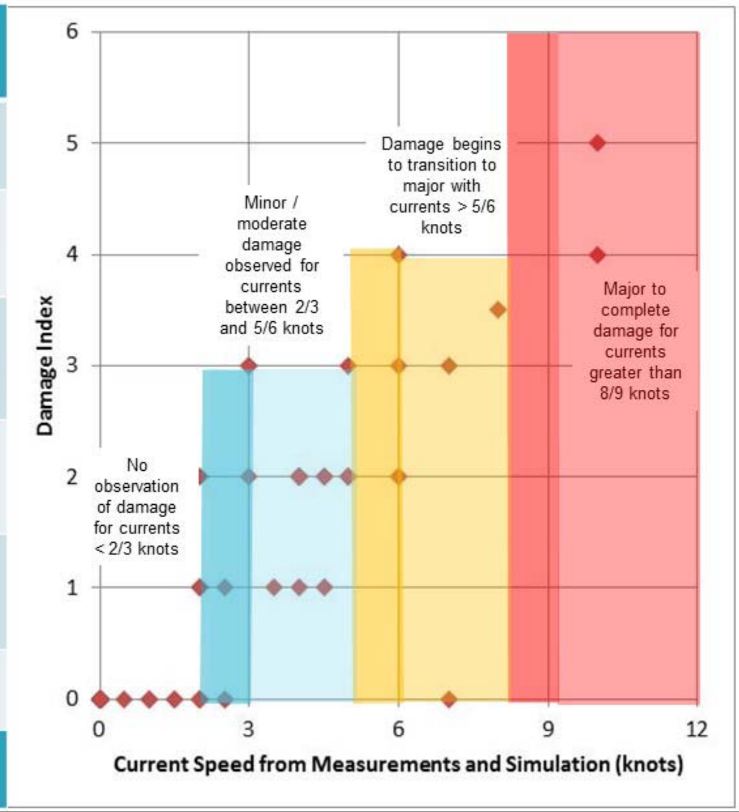

Figure 2 Graphic showing the relationship between strong tsunami currents and damage in a number of harbors and real events. The red points represent damage-current data from past events and tsunami modeling (modified from Lynett and others, 2013).

Figure 3 illustrates that three current threshold divisions can be used to categorize potential damage levels in analysis of tsunami currents in ports and harbors. The maps can be displayed as individual scenarios representing a variety of potential size events, or all scenarios can be combined onto one single map to demonstrate what the "worst case" conditions might be throughout the harbor.

Model results should be carefully reviewed to ensure eddy formation and movement are accurately captured. Figure 3 shows an example of how these areas of potential eddies or strong currents not fully defined by the modeling can be identified for maritime planners.

The final products should be in line with what the maritime communities and the local emergency managers would like to use in response and mitigation planning. When displaying multiple scenarios, the colors chosen to represent and distinguish the current thresholds should have a consistent scale for the best comparison.

Figure 3 Example maps from Santa Cruz Harbor showing potential damage based on strong currents generated by a tsunamis of different amplitudes (modified from the Maritime Tsunami Response and Mitigation Playbook for Santa Cruz Harbor, 2015). Note the addition of dashed ovals identifying where damaging eddies may form and travel.

Product 3: Identification of Areas of Potentially Large Water Fluctuation

Sudden large fluctuations in water levels during a tsunami can lead to a variety of hazards inside harbors. As the water level shallows, the keel of boats can be damaged by impact with the seafloor or may become stuck in muddy bottom sediment or debris. Vessels moored alongside docks and piers can torque and break mooring lines and/or collide with the docks themselves and cause damage. Boats can also float onto the top of docks and piers and docks could overtop piles if water levels rise suddenly. Relocating ships during a tsunami is not recommended as large drops in water level could create very shallow conditions in navigation channels.

An approach to include both transient and regular water-level fluctuations has been developed as part of the California Playbook Series. The approach incorporates tidal and storm conditions at the expected time of tsunami arrival within computed error bounds. The tsunami Forecast Amplitudes, Storm and Tidal conditions, Errors in the modeling, and Run-up potential (FASTER) method (Wilson *et al.*, 2014),provides a true water elevation prognosis, which can help to indicate how high the water will get within a harbor, and thus can help to identify any docks that might overtop piles and any areas of normally dry land expected to flood. Appendix B provides more detailed information about FASTER method. Figure 4 provides an illustration of how the FASTER water elevation value might be utilized in real-time to determine whether or not water level will be high enough for docks to overtop piles.

Guidance:

Maps indentifying the amount of total water level change as well as the highest and lowest water level related to a set elevation or (tidal) datum (Figure 5 and 6) could be developed. In the absence of modeling, harbors can measure the height of the lowest piles and lowest shoreline to understand at what point docks may overtop piles or dry-land inundation might first occur. When modeling is planned for a specific harbor or port, the following steps should be followed to produce tsunami hazard maps that will help identify potential areas of large water fluctuation (peak and trough elevations) and where shallow harbor conditions might occur during an event:

1) Consider scenarios with significant potential tsunamis and utilize modeled time history results from the suite of runs to develop a map that shows the difference between the maximum peak and trough amplitudes through the harbor.
2) Using a common tidal datum, subtract the layer showing the maximum trough or low water from the bathymetric DEM. Areas of negative values will represent the potential areas where the harbor bottom will be exposed, as well as shallow areas within the channels exist. Calculating the maximum low tsunami water level from a Mean Lowest Low Water datum will provide the "worst case" for exposed areas.
3) Identify the expected high water level. The modeled maximum flow depth added to the Mean Highest High Water datum can be used to identify how high water can get. This could be compared with elevations of permanent piers and docks to see where ships might overtop them. Ensure that all comparisons are based on the same vertical/tidal datum or zero elevation.

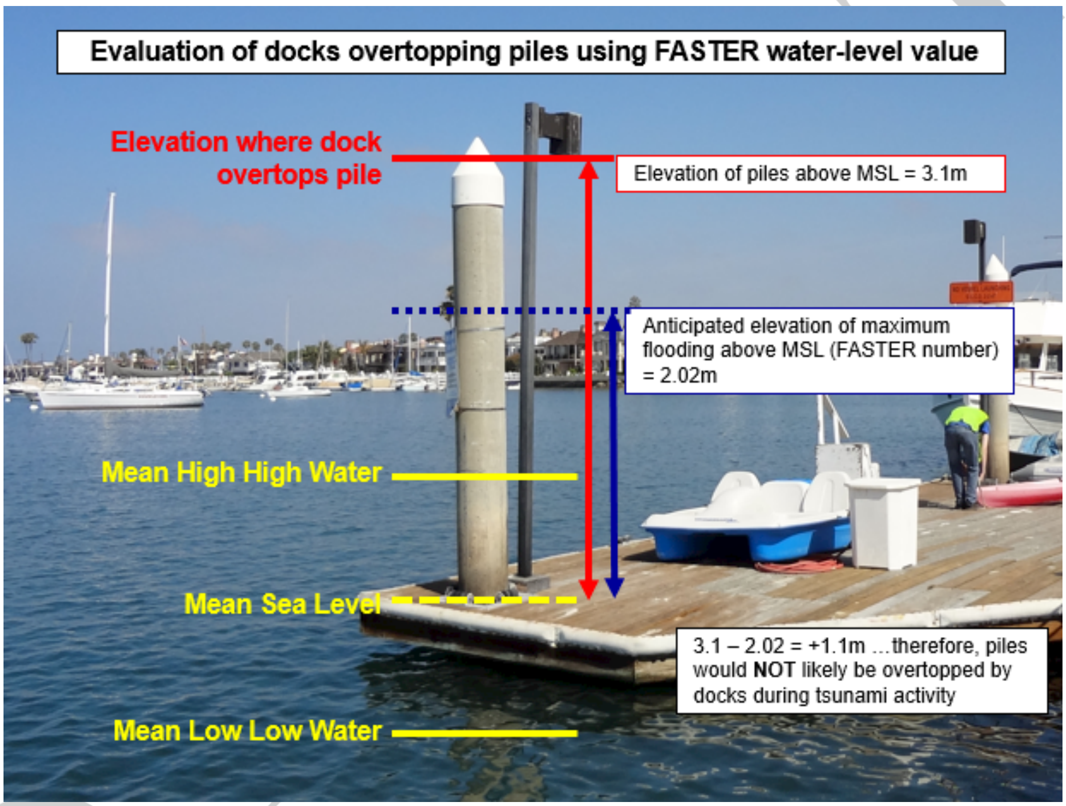

Figure 4 FASTER water-level value or elevation considers tsunami amplitude, tidal height, and storm surge level. It represents the potential maximum flood elevation during tsunami activity (different than tsunami amplitude by itself). The FASTER number can be compared to the absolute pile height to help determine if docks will overtop piles or tsunami flooding will inundate dry land around harbor.

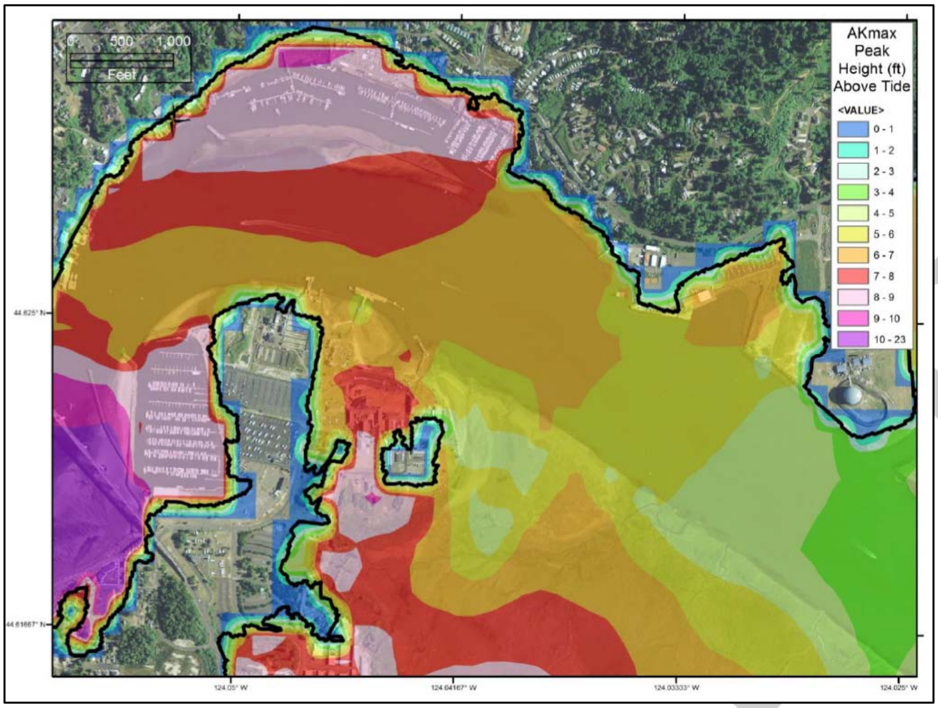

Figure 5 Maximum height above tide map in Newport, Oregon, for a maximum-considered tsunami from Alaska. Note that the Mean Higher High tide is 7.6 feet above geodetic Mean Sea Level (NAVD88). Black lines represents the maximum tsunami inundation. (Figure provided by George Priest, Oregon Department of Geology and Mineral Industries)

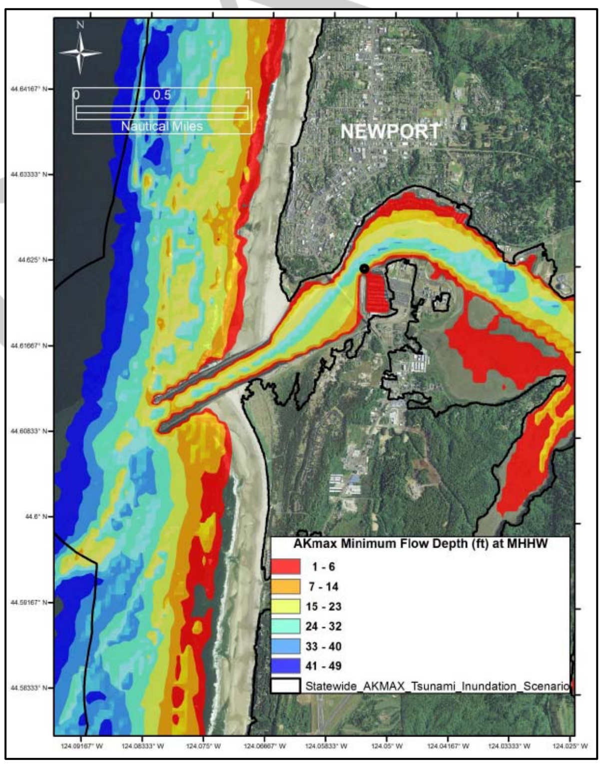

Figure 6 Minimum tsunami flow depth of Newport, Oregon, for a maximum-considered tsunami from Alaska. Mean Higher High Tide is 7.6 feet NAVD88. (Figure provided by George Priest, Oregon Department of Geology and Mineral Industries)

Product 4: Identification of Areas of Potential Bores, Seiches, and Amplified Waves

Bores and amplified waves, as well as other unique tsunami conditions, may cause damage to portions of harbors where wave activity is uncommon. Bores typically occur in rivers or inside channels where a tsunami may be funneled. As was observed during the 2011 tsunami, a number of single, amplified waves over one-meter in height were generated and subsequently propagated deep into the Santa Cruz Harbor three hours after first arrival of the tsunami from Japan. As seen in Figure 7, these tsunami waves caused significant damage to docks and boats (Wilson *et al.*, 2012a).

Figure 7 Photo showing one of several single, amplified waves that entered into the back half of Santa Cruz Harbor, causing damage to a number of docks and boats (from Wilson and others, 2012a).

Guidance:

Numerical models may be able to capture bores, however seiches and amplified waves which can occur hours after the first wave arrival are difficult to model. The following steps should be followed:

1. Review historical records and observations to determine if bores, seiches, or amplified waves have occurred.
2. Evaluate the shape and depth of the harbor/port to determine the potential for bores, seiches, or amplified waves to occur.
3. If the characteristics of the harbor/port are consistent with causing these effects, run a numerical model which bests captures bores, seiches, or amplified waves.
4. If modeling does not work, the modeler can identify on a map or within the text of the guidance where these effects might take place.

Product 5: Identification of Timeframe for Damaging Currents

The duration of strong, damaging tsunami currents is of great importance to harbor masters and emergency managers for tsunami planning and response activities to enhance public safety for mariners. Kim and Whitmore (2013) demonstrated that tsunami signal duration can be estimated from maximum amplitude at locations, though the range of uncertainty is large. Lynett *et al.* (2013) captured the envelope of wave heights and current velocities decay in numerical models run for a 60-hour tsunami period. Of note, however, is that the authors found little phase correlation between model results and measured data. The information is none-the-less useful and can provide a general timeline of activity for specific strong currents.

Guidance:

The duration of damaging currents could be provided in "time-threshold" maps. For a specified current velocity level, these maps will show the time duration during which the velocity is exceeded based on numerical modeling results run for a 60 hour tsunami scenario. It is recommended that the duration represent the time period between the first and last time a particular velocity is exceeded, not the sum of times the threshold is exceeded. While this type of information should be very useful for harbor personnel to estimate the duration of dangerous conditions, the estimates will be highly source dependent and scenario specific. Figure 8 shows an example of what these maps might look like (Lynett *et al.*, 2013).

The following steps can be taken to produce time-threshold maps:

1) Use the modeled time-history data for various scenarios to determine the length of time specific current thresholds (3/6/9 knots for well-maintained harbors; 2/5/8 knots for older, poorly maintained harbors) are active.
2) Maps can be created that show the same time-threshold for multiple scenarios (Figure 8), or multiple time-thresholds for the same scenario (Figure 9).
3) When displaying multiple time-thresholds on a maps, the colors used for the times should have a consistent scale for the best comparison.

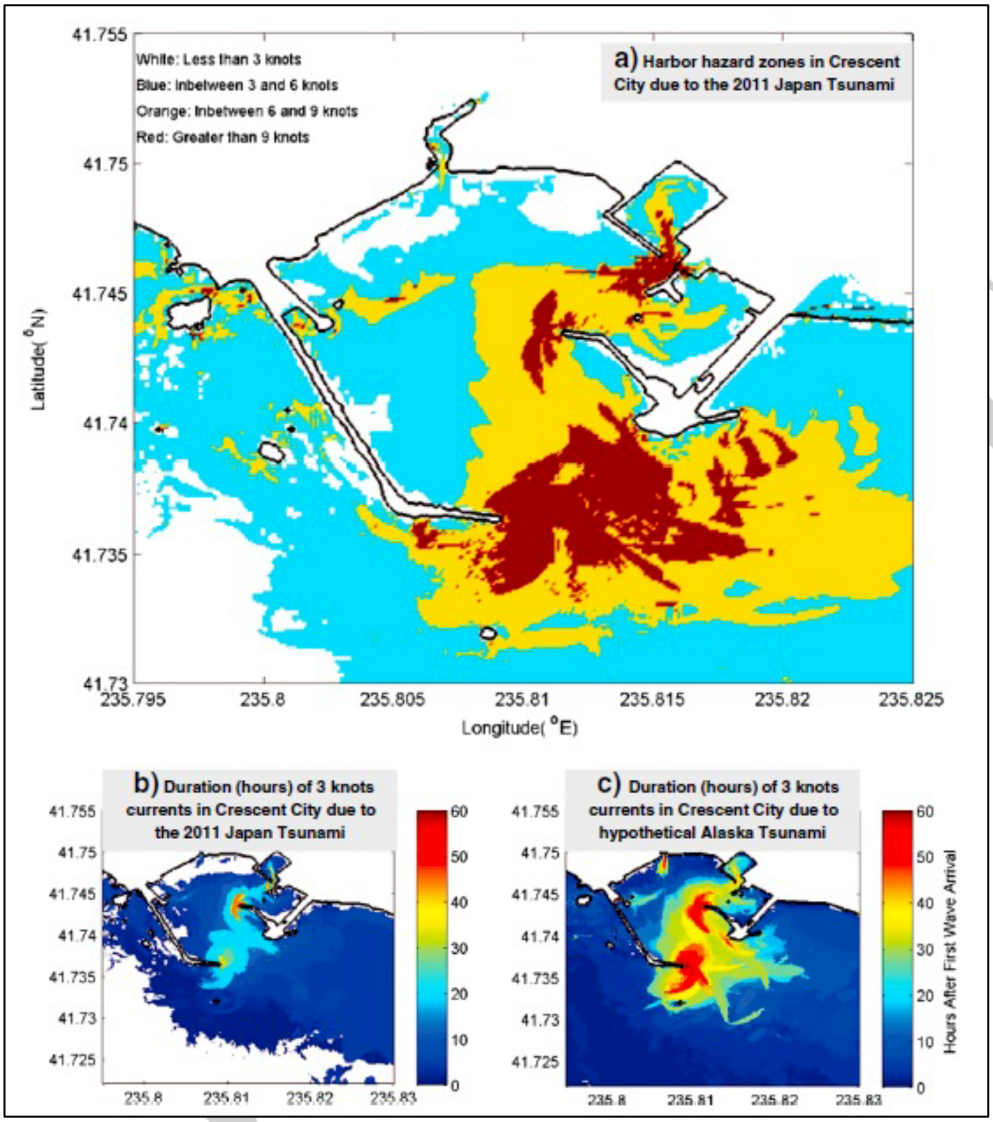

Figure 8 Example uses of the current speed hazard zones for 3/6/9 knot zonation, and time-threshold maps for two different sources in Crescent City Harbor (from Lynett and others, 2013).

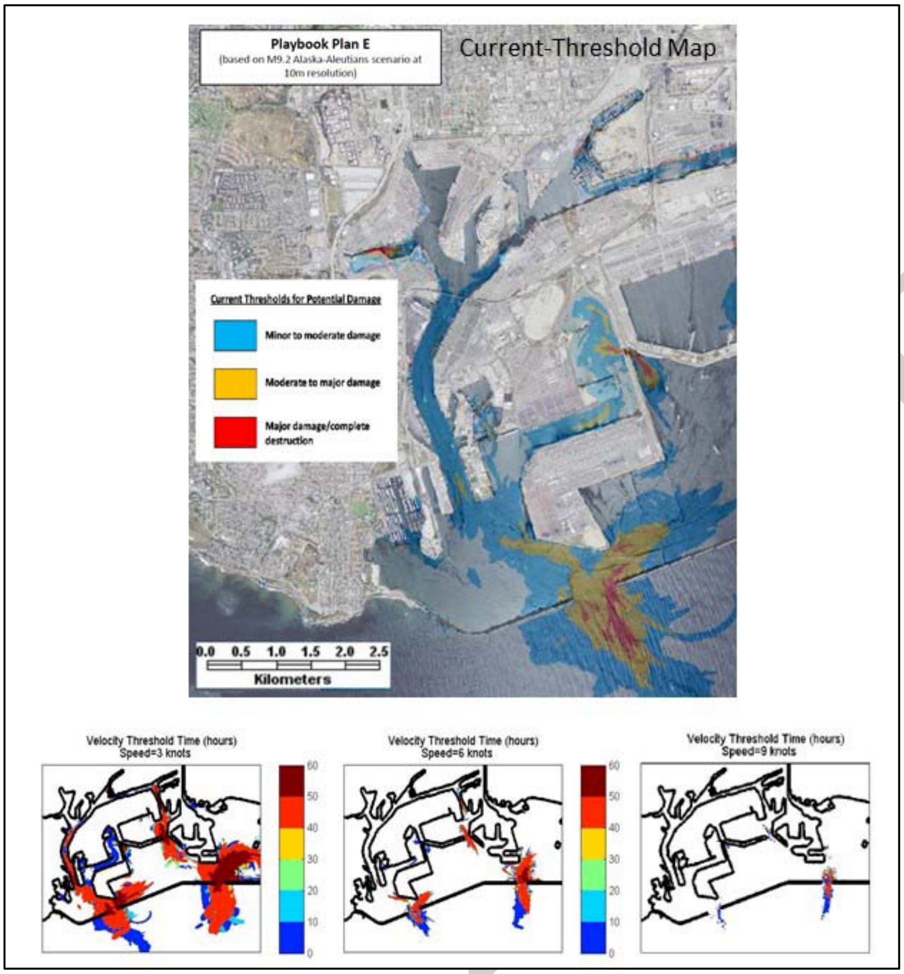

Figure 9 Example of current velocity-damage threshold map (3/6/9 knots), and time-threshold maps for each of the current-damage thresholds in the Port of Los Angeles (modified from the Maritime Tsunami Response and Mitigation Playbook for the Port of Los Angeles, 2015).

Product 6: Identification of Safe Minimum Offshore Depth

Boat owners and captains should NOT be on their boats during a tsunami. However, if mariners have few options, are experienced boat handlers, and are prepared to remain at sea for up to a 24-hour period, they may attempt to take their vessel out of harbor and transit offshore. In the event of a distant-source tsunami where there is sufficient time to safely move or evacuate vessels from a harbor, or in the event where vessels are already at sea, whether or not a distant or local tsunami has been generated, offshore evacuation areas can be provided for guidance. As most ship captains will be familiar with following fathom lines, a "safe minimum depth" where hazardous conditions are not expected should be specified in fathoms. There are a number of conditions that should be met in order for a depth to be recommended as "safe." Such conditions include no chance of vessel grounding, negligible wave steepness, and navigable currents. From observations of tsunami induced coastal currents in previous events, the dominant challenges to coastal navigation are due to both strong currents and currents that are rapidly changing in both time and space. Whether or not there is enough time to reach a designated safe depth is a crucial decision trigger point for whether or not vessels should attempt to evacuate out to sea at all.

The general recommendation from NOAA has been to travel beyond a depth of 100 fathoms (600 feet). This guidance is generally considered to be overly conservative and, along some coastal locations, unrealistic. Recent analyses in California and Oregon indicate that a 30 fathom (180 foot) depth is reasonable along the Pacific coast of North America following generation of a tsunami at a distant source (Lynett *et al.*, 2013; Oregon Marine Advisory Committee, 2014). The California analysis included a scatter plot of maximum currents versus water depth (Figure 10). The plot shows that maximum tsunami currents of less than 1 knot [0.5 m/s] are expected at a depth of 100 fathoms. Large variations in the possible maximum current exist to a depth of approximately 25 fathoms [150 feet], indicating that this is the greatest depth that large eddies or jets might extend to. This type of analysis was performed at five harbors in California. The results from these five cases led were consistent and led to the California Tsunami Steering Committee accepting a safe depth of greater than 30 fathoms, particularly for dispersed or larger vessels.

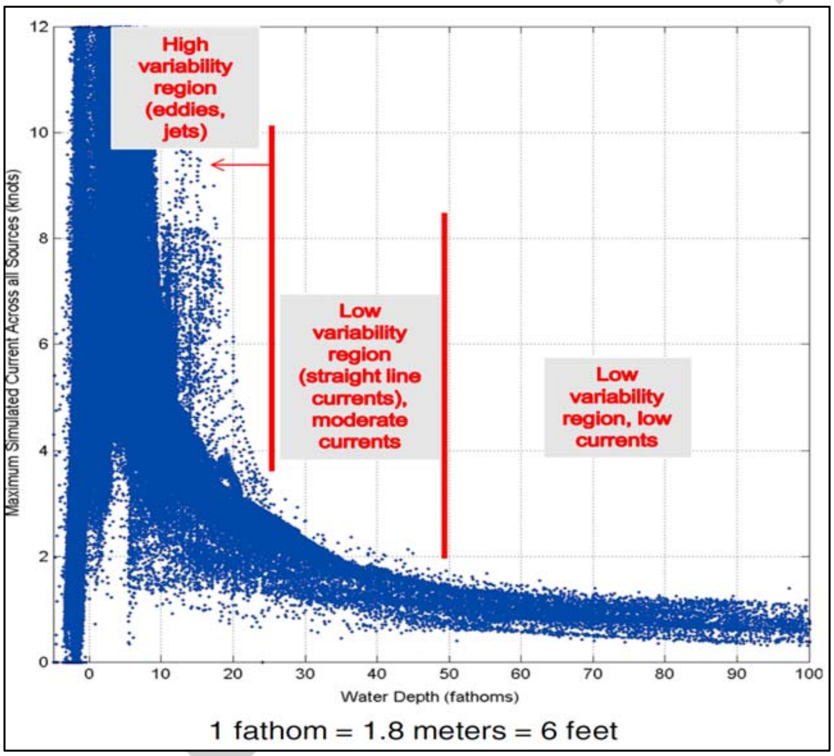

Figure 10 Scatter plot of maximum modeled current velocity versus water depth at Crescent City Harbor (Lynett and others, 2013).

The State of Oregon formed a Maritime Advisory Committee (MAC) to address the offshore safe depth issue. Their analysis included review of numerical modeling results of strong currents during a large local source (Cascadia) and a large distant source (Alaska). The potential for offshore vortices were also analyzed. Committee findings are summarized in Figure 11. With current velocities less than 3 knots considered ideal for a safety, the State of Oregon determined that the safe depth for distant source events should be 30 fathoms, but that vessels at sea during a local Cascadia source event should steam to a depth of 100 fathoms.

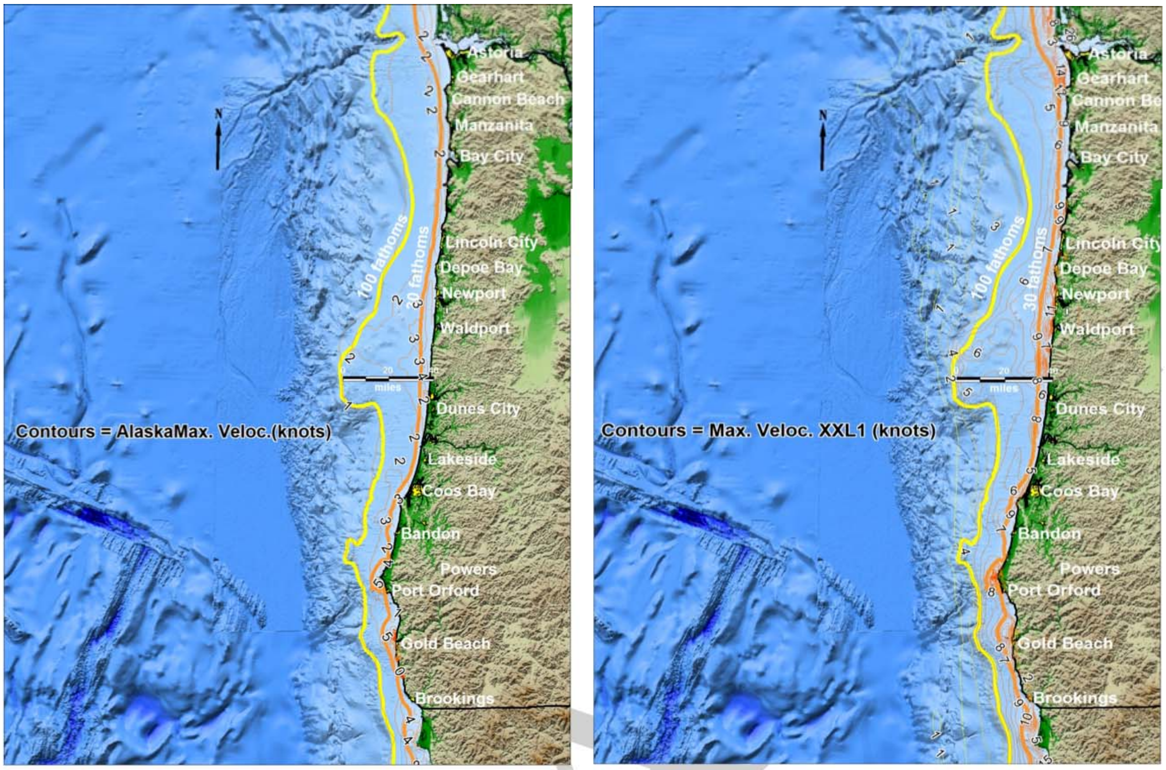

Figure 11 Maximum tsunami current maps for a modeled large Alaska scenario and a large Cascadia scenario (Oregon MAC, 2013).

Guidance:

The NTHMP is working with the U.S. Coast Guard to establish offshore safety guidance for all U.S. coastlines based on the analysis being done by many states/territories. This guidance will include overarching recommendations for all members and vessel sizes of the boating community, including recreational, commercial, and large vessels. Because of the unique character and bathymetry of U.S coastlines, a single minimum offshore safe depth may not be practical. Regional guidance is being developed, a summary of which is provided in Table 2.

Table 2 Specific guidance for minimum offshore safe depths for maritime vessel evacuation prior to the arrival of tsunami.

State/Territory	Minimum offshore safe depths		Notes
	Distant Source Tsunami	Local Source Tsunami	
California	30 fathoms	100 fathoms	Evaluated, except for the San Francisco Bay*
Oregon	30 fathoms	100 fathoms	Evaluated
Hawaii	50 fathoms	50 fathoms	Evaluated; implemented in Coast Guard plan in some locations
Alaska	30 fathoms & vessels should be at least 1/2 mile from shore	100 fathoms	Evaluated

Washington	30 fathoms	100 fathoms	Evaluated, special conditions inside Puget Sound*
Puerto Rico	50 fathoms	100 fathoms	Evaluated
US Virgin Islands	50 fathoms	100 fathoms	Evaluating; Possibly follow PR*
Gulf Coast		100 fathoms	Evaluating*
East Coast		100 fathoms	Evaluating*
American Samoa	50 fathoms	50 fathoms	Evaluating*
Guam	50 fathoms & vessels should be at least 1/2 mile from shore	100 fathoms	Coordinated with USCG Guam Sector
Commonwealth of Northern Mariana Islands	50 fathoms & vessels should be at least 1/2 mile from shore	100 fathoms	Coordinated with USCG Guam Sector

*Please contact the MMS state representative for the further information.

Maritime evacuation maps are recommended to be created using 30, 50, and 100 fathom lines. In addition, more detailed and controlled vessel evacuation plans are recommended for harbors. For example, the U.S. Coast Guard has developed a maritime evacuation plan for some harbors and ports along the southern coast of Oahu, Hawaii. This plan is shown in Figure 12 as an example of what other maritime communities might consider replicating. Although this will likely be addressed in more detail in the preparedness and response section of this guidance, maps like these will help the maritime community better visualize evacuation.

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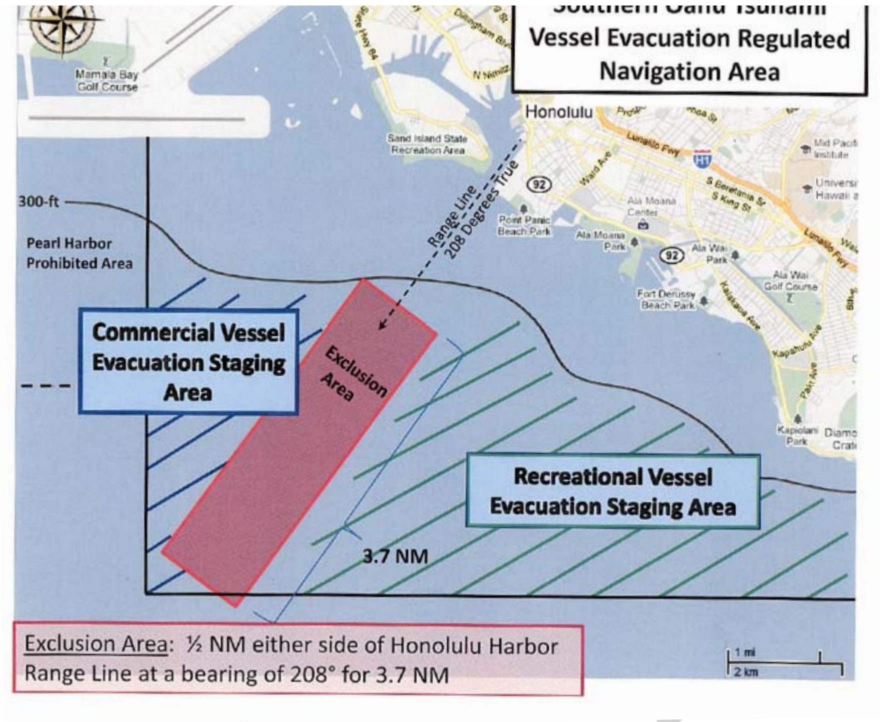

Figure 12 Map showing maritime evacuation plan for vessels in the port at southern Oahu (from Coast Guard, 2013).

Other Products

In addition to the tsunami hazard products discussed above, there are other potential products that can assist harbor masters and emergency managers with their preparedness, mitigation, and response planning activities. These products are either very specialized, less common, or less vetted compared to the tsunami hazard maps and products discussed previously.

- Sediment Movement – Evaluation of sediment movement during a large tsunami enable harbors to determine if mitigation measures such as sediment control structures or additional dredging are needed. Dredging of sediment in a post-tsunami environment could be costly because of the high potential for sediment contamination due to fuel leakage or other toxic contamination. Wilson *et al.* (2012b) evaluated sediment movement within Crescent City and Santa Cruz harbors during the 2011 Japan tsunami (Figure 13). Differencing pre- and post-tsunami bathymetric survey data helped identify where sediment erosion and accumulation occurred. It is important that post-tsunami bathymetric data be collected as soon as possible after the tsunami to reduce the potential addition of sediments from background erosion/sedimentation in the harbor. It is also important to make sure that all bathymetric data are set to or corrected to a common vertical datum. Cross sections from the bathymetry and sediment cores can also be a useful product for harbor recovery planning.

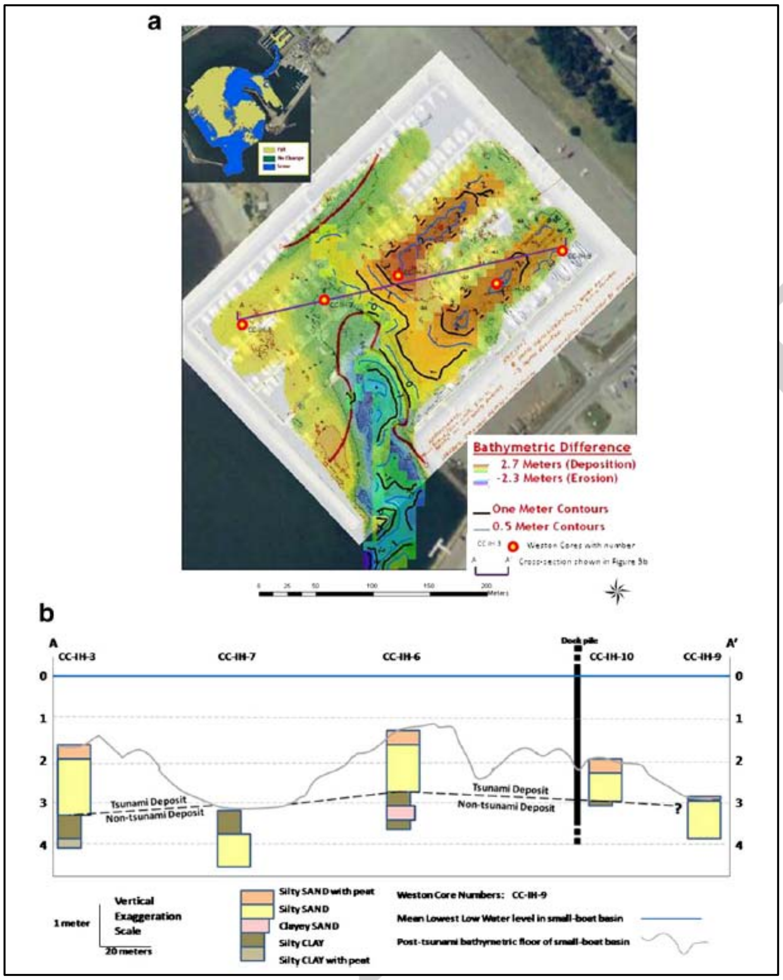

Figure 13 Areas of scour and fill in the Crescent City Harbor Small-Boat Basin determined by differencing multi-beam bathymetric data. The cross section shows the post-tsunami sediment composition and correlation between tsunami and non-tsunami deposits (from Wilson and others, 2013b).

- Debris Movement Models – Even in cases where ships and docks may seem safe from direct damage from strong tsunami currents or water-level fluctuations during certain events, loose debris may make any location within harbors susceptible to damage. Analysis of debris movement is an evolving field of study but there have been some new modeling tools which could help harbors visualize where debris might come from and where it might travel. Lynett (unpublished) is developing a debris model that is based on simple particle movement within his current models. Figure 14 is a screen shot from a debris/particle movement model in the Port of Los Angeles. The time-history movie from which this figure was extracted, showed potential debris movement and demonstrated that although large ships within the Port were safe from direct tsunami damage, debris from the small boat harbors could damage larger ships and harbor infrastructure or block navigation channels.

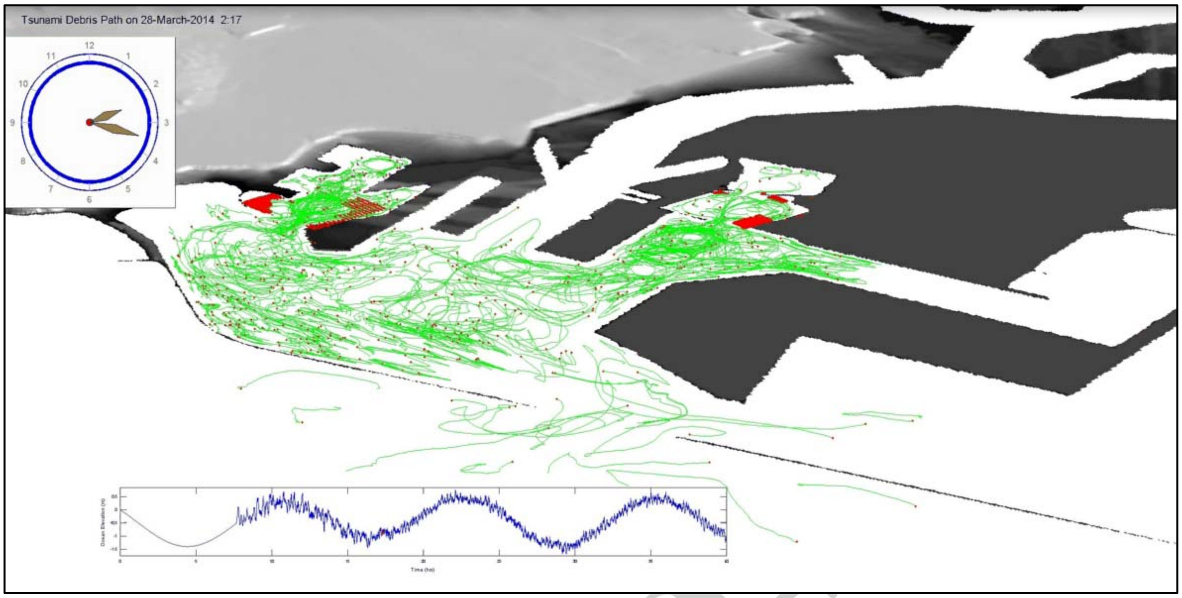

Figure 14 Modeled debris/particle movement from small-boat basins within the Port of Los Angeles (Lynett, unpublished).

- Mitigation Analysis and Products – Many harbor managers are interested in understanding the vulnerability of their harbor facilities and infrastructure to tsunami damage. Although this requires a more engineering based analysis, some simple tsunami hazard map products can help harbors determine where first-order problem areas exist. For example, Keen *et al.* (2016) have started developing failure probability curves for cleats and moorings based on the velocity and direction of flow. These curves are compared to the tsunami velocity and direction from various scenarios for different parts of a harbor to determine the potential for failure during these scenarios (Figure 15). These types of analyses will help harbors pin-point where dock and infrastructure improvements could be implemented. The way that these products can be incorporated into hazard mitigation planning will be discussed in a later section of the guidance.

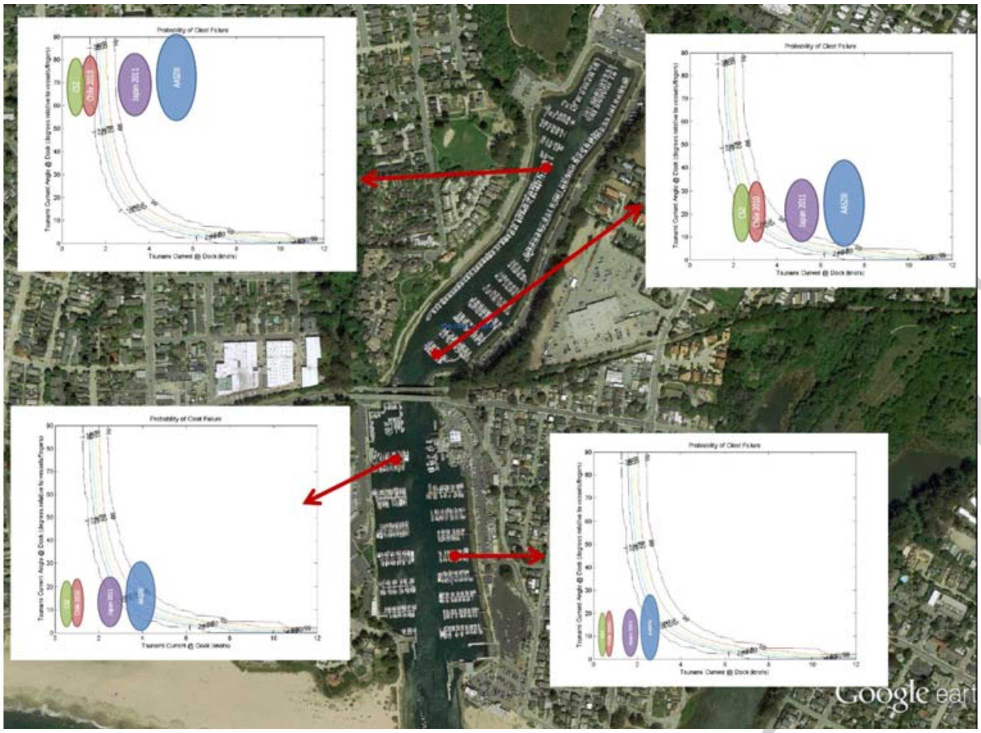

Figure 15 Failure probability curves for cleats in Santa Cruz Harbor. The current speed and direction for various modeled scenarios have been added to the curves for reference, to help determine what portions of the harbor might be most vulnerable.

1.3 Basic Guidance on Design of Products

Maritime tsunami hazard preparedness products may include maps and plans that are printed, digital files, or interactive/web-based, especially for harbor-specific planning products. In order to develop products that are consistent between states/territories, the following is general guidance for products:

Mapping:

- All maps and products should include a title, scale, geographic location (coordinates), intended use, and appropriate explanatory information.
- All maps and products should reference technical documentation on how the map was made and its intended use.
- Maps should include streets, bridges, and other landmarks. Where appropriate, escape direction arrows and assembly areas should be included to help people identify the avenues of egress and safe locations on land.
- Maps and products should be legible for all users, including people with color vision disabilities.
- Communities should consult with the producers of tsunami hazard maps and products when developing preparedness, response, and mitigation plans so that the intended accuracy and limitations of these products are considered. Consult with your NTHMP Scientist or Emergency Manager (see the NTHMP web site http://nthmp.tsunami.gov/ for a current list of contacts).
- In addition to printed form, tsunami hazard maps and products should be made available digitally, considering the scale limitations and appropriate base maps, to facilitate outreach.
- In the absence of other tsunami hazard information, and where Hurricane Storm Surge Maps are available, use the Storm Surge Atlas Maps in consultation with your NTHMP scientific representative, for tsunami evacuation planning.
- Develop products in multiple languages where warranted.

- If appropriate, simplified instructions on what to do in event of a tsunami should be included on the final map products.
- If in an electronic form, a GIS-based shape or KML overlay file of the evacuation route will be developed for tsunami hazard maps. Communities who do not have the resources to create these files can contact their State NTHMP Partner for support.

Symbols:

- Recommend a modified adoption of the Homeland Security Mapping Standard symbols, found in ANSI INCITS 415-2006. They are available as a true type font at www.fgdc.gov/HSWG
- Symbols should be black. If they are against a dark background, a line of white should separate the symbol from the background image.
- Symbols should be easily perceived in terms of size and scalable according the size of the final map product.
- Symbols should have precise meaning without a need for explanation on the map other than in the legend.

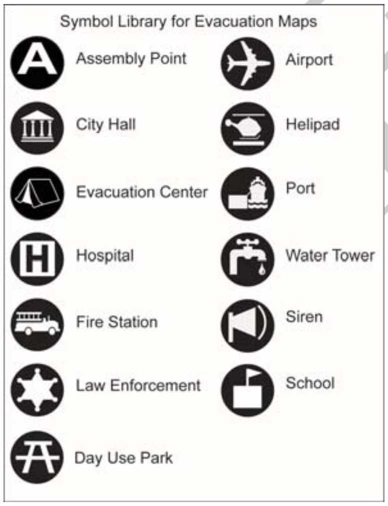

Figure 16 Standardized mapping symbols

Colors:

- A color wheel of cool (white/clear, blue, green) to hot (yellow, orange, red) colors should be used to demonstrate low to high hazard areas, respectively.
- If colors other than those suggested are selected, every effort should be made to ensure that the publication is readable by the color blind. Avoid putting the color red next to the dark green color.
- Color maps should be reproducible in black and white.

Palette for tsunami evacuation mapping guidelines

		RGB Values	CMYK Values	Hexidecimal
Yellow		255 242 0	0 0 100 0	#FFF200
Orange		251 169 25	0 38 100 0	#FBA920
Red		230 6 15	3 100 100 1	#E6060F
Blue		12 7 248	88 78 0 0	#0C07F8
Cyan		0 174 239	100 0 0 0	#00AEEF
Dark Green		74 140 3	75 23 100 8	#4A8C03
Light Green		161 187 132	40 13 60 0	#A1BB84

Figure 17 Suggested standardized colors for tsunami hazard maps and products.

Part 2: Guidance for Tsunami Response, Preparedness, and Education

The following guidance is currently being developed and is not final

2.1 General Maritime Guidance

A number of tsunami response, preparedness, and education resources exist for states, territories, and communities to use in their maritime communities. Recommended actions have been developed by Puerto Rico, Hawaii, California, and Oregon. Japan has also developed similar types of recommended actions for harbors and the boating community.

From the Oregon Department of Geology and Mineral Industries, 2013:
TSUNAMI! What Oregon Boaters Need To Know

Distant Tsunamis: *You generally have at least 4 hours after the distant earthquake to take action.*

If you are on the water

- Check with the US Coast Guard (USCG) before taking any action. If advised that offshore evacuation is an option and this option looks practical for your vessel, proceed to a staging area **greater than 30 fathoms (180 ft)**. If conditions do not permit, dock your boat and get out of the tsunami evacuation zone.

If you are on land or tied up at the dock

- Your choices are to a) evacuate out to sea beyond 30 fathoms, b) leave your vessel and evacuate out of the distant tsunami inundation zone, or c) go upriver. DO YOUR HOMEWORK before the event to understand how practical these options are for the largest distant tsunamis that might strike your area. Check with local authorities and www.oregontsunami.org for information.
- Check with local authorities before taking any action. Most distant tsunamis are small enough that it is safer to keep your boat docked. Congestion in the waterway or among those trying to pull boats out with trailers can create serious problems. Sea and weather conditions may be more dangerous than the tsunami! Get yourself out of the tsunami evacuation zone.

After the tsunami

- If in an offshore staging area, check with the USCG for guidance before leaving the staging area; conserve fuel by drifting until you know what actions you need to take.
- If in an onshore assembly area, check with local authorities for guidance before returning to the inundation zone.

Local Tsunamis: *You have only ~10 minutes to take action, so have a plan ahead of time that includes a quick way to release commercial fishing gear so your boat is not dragged down by currents; have at least 3 days of food, fuel and water.*

If you are on the water

- At less than 100 fathoms (600 ft): (1) Stop commercial fishing operations immediately, (2) free the vessel from any bottom attachment (cut lines if necessary), and (3) if you can beach or dock your boat and evacuate on foot within 10 minutes of a natural warning, then this is your best chance. If that is not possible, head to greater than 100 fathoms, keeping in mind the following:
  - Proceed as perpendicular to shore as possible.
  - Sail directly into wind waves, keeping in mind that wind waves opposed by tsunami currents will be greatly amplified.
  - Maintain as much separation as possible from other vessels.
  - Synchronize movements with other vessels to avoid collisions.

- At greater than 100 fathoms: If you are in deep water but not quite 100 fathoms, head to deeper water. If you are already at greater than 100 fathoms, then you are relatively safe from tsunamis, but deeper water is safer from tsunami currents and the amplification of wind waves by those currents.

If you are on land or tied up at dock

- Evacuate out of the tsunami evacuation zone. You don't have time to save your boat and could die if you try to do so.

After the tsunami

- If in an offshore staging area, check with the USCG for guidance before leaving the staging area; conserve fuel by drifting until you know what actions you need to take.
- If in an onshore assembly area, check with local authorities for guidance before returning to the inundation zone.
- Do not return to local ports until you have firm guidance from USCG and local authorities.
- Local ports will sustain heavy damage from a local tsunami and may not be safe for days, weeks or months.
- If at sea, check to see if you can reach an undamaged port with your current fuel supply and watch for floating debris or survivors that may have been washed out on debris.
- If at sea, consider checking with USCG about your role in response and recovery.

From Japanese Ministry of Agriculture, Forestry, and Fisheries, 2007: *BASIC ACTIONS FOR TSUNAMI THREAT SITUATION ACTION*

Fishing boats at or off-shore

- Immediate evacuation to the pre-decided designated sea area in advance of the 1st tsunami wave arrival; deeper than 50 meters (27 fathoms)
- If a large tsunami is confirmed, move to deeper-depth sea area
- Do not come back to the harbor until Tsunami Cancellation is issued

Fishing boats in harbor

- Estimation of tsunami arrival time to harbor should be known.
- If there is enough time, fishing boats can evacuate to the designated sea area. If no time, boats should be left and persons should immediately evacuate to the safe place on land.

Fishery operators in harbor

- Keep away from the harbor and immediately evacuate to the pre-designated safe place.
- Local people shall escort visitors

Fishery operators on land (in house, factory, stores, etc)

- Do NOT go to the harbor to check the fishing boats.
- Any action in harbor
- Immediate evacuation on foot

Workers and visitors on the beach

- Keep away from the beach and immediately evacuate on foot to the pre-designated safe place.
- Local people shall escort visitors

Residents, workers and visitors on land

- Immediately evacuate on foot to the pre-designated safe place.
- Local people shall escort visitors

2.2 Harbor/Port Specific Maritime Guidance

In some cases, general maritime guidance may not be sufficient to adequately prepare ports and harbors for tsunamis of different sizes, especially where damage has occurred during past events. Harbor/Port specific guidance may be more appropriate, the benefits of which address:

- The characteristics unique to each harbor/port, especially size and layout relatedin relation to potential tsunami hazards;
- The harbor response to tsunamis of varying sizes and source locations; and,
- Identification of potential hazardous and non-hazardous areas within each harbor.

Alert-Level Tsunami Response Guidance (Appendix A) and Scenario-Specific Tsunami Response Playbooks (Appendix B) provide two examples of these harbor-specific response planning guides. Alert-Level Guidance was developed by the State of Oregon based on tsunami response activities on the two actionable tsunami alert levels: Advisories and Warnings. Scenario-Specific Playbooks were developed by the State of California and it bases the tsunami response activities on model results from multiple scenarios ranging from small Advisory to large Warning events.

Oregon and California worked together to make their harbor-specific guidance documents as consistent as possible in appearance and content. Although the treatment of response levels in the developed approaches are somewhat different, the information and formats of the harbor-specific guidance documents include many of the same sections: actionable tsunami alert information; notable historical tsunamis; tsunami current velocity maps; recommendations on minimum safe depths for offshore evacuation; tsunami evacuation maps/plans; and real-time and permanent mitigation measures. Ultimately, the decision to produce harbor-specific tsunami response plans will depend on the needs and capabilities of a specific maritime community as well as the funding available to complete the modeling, guidance, and plan activities.

Alert-Level Tsunami Response Guidance:

An example of Oregon's tsunami response guides entitled "Maritime Guidance for Distant-Source Tsunami Events" is presented in Appendix A. The guides help maritime communities prepare, plan, and respond to Advisory- and Warning-level alert tsunamis. The plan can be referenced in real-time during an approaching tsunami.

For background, tsunami Advisories are forecasted by one of the two NWS Warning Centers when expected tsunami amplitudes (sea surface to wave peak), or wave heights (wave peak to adjacent trough), are between 0.3m and 1m; tsunami Warnings are forecasted when amplitudes are above 1m in height. Both alert levels indicate the possibility for strong currents in harbors, ports, and bays but a Warning alert level implies that inundation of dry land might also occur.

It is recommended that the guidance only be used for tsunamis with travel times greater than 4-5 hours. This would allow sufficient time for maritime communities to initiate emergency response plans which might include strengthening harbor infrastructure and boat moorings, or relocating boats within or outside the harbor. The tsunami current maps can also be used to assist harbors and port in making structural improvements to their harbor facilities.

Scenario-Specific Tsunami Response Playbooks:

An example of the Maritime Tsunami Response "Playbook" developed by the State of California is presented in Appendix B. The playbook was designed to assist maritime communities plan and respond to tsunamis of various sizes. This approach was envisioned following the 2010 and 2011 tsunamis, where damage varied greatly depending on the size of the incoming tsunami (Wilson *et al.*, 2012a). The multi-scenario playbook planning strategy relies on the direct relationship between tsunami amplitude and tsunami currents in harbors. Harbor-specific information helps harbor officials develop detailed response plans for at least five scenarios in the Advisory to Warning-level range. Harbor officials can develop an action plan for each scenario and then reference the appropriate plan during future tsunamis.

Using a sports analogy, the Playbook approach provides the best coastal defense for a tsunami of a particular size and source location. The correct "Play" (or "Plan") is used to combat or defend against a tsunami that is on the offensive. Similar to Oregon's response plans, the Playbooks should only be used if there is sufficient time for strengthening harbor infrastructure and relocating vessels.

To use the Playbooks in real-time, it is anticipated that once the Tsunami Warning Center(s) provides a forecast of peak wave amplitude (sea surface to peak, or ½(wave peak to trough)), which may take 1-3 hours after the tsunami is first generated, it should take only 15 minutes to determine the appropriate MINIMUM Playbook Plan for use by each maritime community because the process is completely automated. Each Response Playbook Plan is associated with a specific tsunami amplitude/wave height and, therefore, will also be determined automatically. The State and NWS will verify the accuracy of Plan recommendation prior to information being shared with harbor officials. Recommendations will only be shared directly with harbor officials and not the public. The reasoning is that local harbor officials and emergency managers ultimately decide on all tsunami response activities. In addition, public response in the absence of direction is unpredictable.

The State and NWS will recommend and communicate a MINIMUM Tsunami Response Playbook Plan for each individual maritime community. The Playbook Plan recommendations will be directly shared with maritime officials via multiple (redundant) communication methods: emails, password-protected websites, etc. The State and NWS will provide further real-time support through appropriate conference calls, individual phone calls and other avenues to make sure the maritime officials understand what this recommendation means. Ultimately, each maritime community is responsible for determining and implementing tsunami evacuations and response. Each community will determine if and how to share the appropriate response plan and activities with their public.

The State of California and FEMA are working in partnership to help maritime communities integrate Playbook hazard information into Local Hazard Mitigation Plans, and develop a strategy for acquiring funding needed to make improvements to structures; some of this work is discussed in the "Mitigation and Recovery" section below.

As previously mentioned, it is important for state/territory/commonwealth entities to meet with and discuss the benefits and limitations of potential harbor/port specific guidance approaches. The following comparison of the approaches is provided for state facilitators to help individual maritime communities determine which harbor-specific planning guide best matches their needs:

	2-Level Response Guidance	**Multiple-Level Response Guidance**
Type of maritime community	Small open-coast harbors or harbors within rivers or bays which have not experienced significant tsunami damage in the past	Harbors and ports which have had damage in past events, especially during both Advisory and Warning level events
Basis for response planning	Response for either Advisory level events or Warning level events	Response specific to multiple scenarios between the Advisory and Warning level range
Scenario modeling required	Minimal modeling required, velocity and flow depth for one or two maximum considered distant source scenario	More comprehensive modeling is required for a variety of distant tsunami sources with the near-shore forecast peak wave amplitude range of 0.3m to 1.5m

Relative cost*	Minor cost for modeling single maximum scenario	Moderate cost for modeling multiple scenarios
Relative accuracy	Moderate accuracy for capturing tsunami conditions	Higher accuracy by selecting response plan with more specific information about severity and location of damaging currents
Decision making and response	Simplified approach with only two choices predetermined by the tsunami alert level	Advanced approach with a number of response choices based on forecast peak wave amplitude from the Warning Center
Real-time decision making assistance from state/NWS	Assistance to select the response level is not required	Assistance to select the response level is recommended; MINIMUM scenario plan may be recommended by state or NWS IDSS

*Cost of modeling will vary. States/Territories should calculate these costs before meeting with harbor/port officials.

Part 3: Guidance for Tsunami Mitigation and Recovery Planning

The following guidance is currently being developed and is not final

3.1 Mitigation Planning Strategies

The NTHMP encourages maritime communities to utilize all tsunami hazard map information to help mitigate damages and loss of life from tsunamis. These products and plans should be used by maritime communities to pre-identify real-time response mitigation measures, determine where infrastructure enhancements are needed, and provide a mechanism for pre-disaster hazard mitigation funding through additions to their Local Hazard Mitigation Plans (see the list of potential mitigation measures below). Although these products, plans, and related mitigation efforts will not eliminate all casualties and damages from future tsunamis, they will provide a basis for greatly reducing future tsunami impacts on life-safety, infrastructure, and recovery in maritime communities. Therefore, we recommend the following steps/actions:

1. Review the maps within the maritime guidance documents to identify where strong currents and other tsunami hazards could potentially damage docks, structures, and/or infrastructure, especially where aging or run-down facilities exist.
2. Review the Mitigation Measures below for both real-time response actions, or "soft" mitigation, or permanent measures, or "hard" mitigation.
3. Incorporate these measures/actions into the community Local Hazard Mitigation Plan, and work with the community, the tsunami program of the state/territory/commonwealth, and/or FEMA to develop a strategy to request funding to implement these improvements.

Mitigation Measures for Reducing Impacts in Maritime Communities	
Real-time response ("soft") mitigation measures	**Permanent ("hard") mitigation measures**
Reposition ships within harbor	Increase size and stability of dock piles
Move boats and ships out of harbors	Fortify and armor breakwaters
Remove small boats/assets from water	Improve flotation portions of docks
Shut down infrastructure before tsunami arrives	Increase flexibility of interconnected docks
Evacuate public/vehicles from water-front areas	Improve movement along dock/pile connections
Restrict boats from moving during tsunami	Increase height of piles to prevent overtopping
Prevent boats from entering harbor during event	Deepen/Dredge channels near high hazard zones
Secure boat/ship moorings	Move docks/assets away from high hazard zones
Personal flotation devices/vests for harbor staff	Widen size of harbor entrance to prevent jetting
Remove hazardous materials away from water	Reduce exposure of petroleum/chemical facilities
Remove buoyant assets away from water	Strengthen boat/ship moorings
Stage emergency equipment outside affected area	Construct flood gates
Activate Mutual Aid System as necessary	Prevent uplift of wharfs by stabilizing platform
Activate of Incident Command at evacuation sites	Install debris deflection booms to protect docks
Alert key first responders at local level	Ensure harbor structures are tsunami resistant
Restrict traffic entering harbor; aid traffic evacuating	Construct breakwaters further away from harbor
Identify/Assign rescue, survey, and salvage personnel	Install Tsunami Warning Signs

Identify boat owners/live-aboards; establish phone tree, or other notification process	Identify equipment/assets (patrol/tug/fire boats, cranes, etc.) to assist response activities

3.2 Recovery Planning Strategies

This section should include the following:

- Alignment with FEMA National Disaster Recovery Framework
- Examples from Chile (2010) and Japan (2011)
- Information from state (OR and WA) resilience plans
- Information from scenarios (FEMA Cascadia, USGS SAFRR)
- CA is working with FEMA and Laurie Johnson Consultants to develop a community guidance and state-level recovery plan

Resources – Maritime References, Products, and Entities

Homeland Security Working Group Emergency Symbology
http://www.fgdc.gov/HSWG/index.html

Field Guide to Humanitarian Mapping
http://www.mapaction.org/images/stories/publicdocs/mapaction%20field%20guide%20to%20humanitarian%20mapping%20first%20edn%20low-res.pdf

Emergency and Hazards Mapping Symbology
http://www.desastres.org/pdf/kentuniversity.pdf

Color Blind Image Corrections
http://www.vischeck.com/daltonize/

Hawaii Coast Guard Maritime Response Plan
http://www.gpo.gov/fdsys/pkg/FR-2013-10-03/html/2013-24150.htm

Hawaii Maritime Planning Guide
http://nws.weather.gov/nthmp/2014mesmms/HawaiiBoaters.pdf

Maritime New Zealand
http://www.maritimenz.govt.nz/Commercial/Safety-management-systems/Safety-management-systems.asp
NOAA Ports Tomorrow Resiliency Planning Toolhttp://coast.noaa.gov/port/?redirect=301ocm#Hazards

Making U.S. Ports Resilient as Part of Extended Intermodal Supply Chains
http://onlinepubs.trb.org/onlinepubs/ncfrp/ncfrp_rpt_030.pdf

Port Recovery in the Aftermath of Hurricane Sandy Improving Port Resiliency in the Era of Climate Change
http://www.cnas.org/sites/default/files/publications-pdf/CNAS_HurricaneSandy_VoicesFromTheField.pdf

Puerto Rico/Caribbean Maritime Planning Guide
http://www.srh.noaa.gov/images/srh/ctwp/TsunamiGuidelinePorts_August2011.pdf

Oregon Marine Advisory Committee

Oregon Maritime Brochure
http://www.oregongeology.org/pubs/tsubrochures/TsunamiBrochureMaritime.pdf

California Maritime Brochure
http://www.conservation.ca.gov/cgs/geologic_hazards/Tsunami/Documents/boating%20pamphlet.pdf

Mitigation of Tsunami Disasters in Ports (PIANC)
http://www.pari.go.jp/en/files/3654/389490581.pdf

California Maritime Tsunami Response Planning Playbooks (examples from: Crescent City Harbor, Santa Cruz Harbor, and Port of Los Angeles)

Lynett, P., Borrero, J., Son, S., Wilson, R., and Miller, K., 2013, Assessment of current-induced tsunami hazards for maritime planning: Geophysical Research Letters.

Keen, A.S., Lynettt, P.J., and Eskijian, M.L., (in progress; 2016), Fragility of floating docks for small craft marinas: American Society of Civil Engineers PORT 2016 conference, June 12-15, 2016; abstract.

National Tsunami Hazard Mitigation Program (NTHMP), 2012, Proceedings and results of the 2011 NTHMP Model Benchmarking Workshop: Boulder, CO; U.S. Departement of Commerce/NOAA/NTHMP; NOAA Special Report; 436 p.

Wilson, R.I., Admire, A.R., Borrero, J.C., Dengler, L.A., Legg, M.R., Lynett, P., Miller, K.M., Ritchie, A., Sterling, K., McCrink, T.P., Whitmore, P.M., 2012a, Observations and impacts from the 2010 Chilean and 2011 Japanese tsunami in California (USA): Pure and Applied Geophysics. http://dx.doi.org/10.1007/s00024-012-0527-z.

Wilson, R., Davenport, C., and Jaffe, B., 2012b, Sediment scour and deposition within harbors in California (USA), caused by the March 11, 2011 Tohoku-oki Tsunami: Sedimentary Geology, doi:10.1016/j.sedgeo.2012.06.001.

Wilson, R., and Eble, M., 2013, New activities of the U.S. National Tsunami Hazard Mitigation Program, Mapping and Modeling Subcommittee: presentation at 2013 American Geophysical Union Fall Meeting, San Francisco, California.

Wilson, R., and Miller, K., 2014, Tsunami emergency response playbooks and FASTER tsunami height calculation: Background information and guidance for use: California Geological Survey Special Report 236; 44 p.