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

Developed by the NTHMP Mapping and Modeling Subcommittee
Draft November 2014

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Purpose of Maritime Planning and Preparedness Guidelines

The purpose of these guidelines is to address the minimum requirements to develop consistent and reliable tsunami preparedness products for maritime communities. Recent tsunamis, including the 2011 Tohoku-Oki event, have caused over $100M in damage to U.S. ports and harbors around the Pacific Ocean. Currently, there is not a consistent approach to analyze, plan, prepare, and mitigate tsunami hazards for these maritime communities. This has led to confusion among the public and incorrect assumptions about the tsunami threat to and actions taken by harbors and boaters. Groups and agencies producing tsunami hazard products and maps, especially with NTHMP funds, are strongly encouraged to adopt these guidelines for maps and related products developed after the guidance is finalized; all other organizations doing similar work are also encouraged to adopt these guidelines.

Intended Audience

These guidelines and best practices are intended for government and non-government entities responsible for the emergency response planning and overall safety of maritime communities. These entities include:

- Federal – NOAA, Coast Guard, other military/Dept. of Defense, US Army Corp of Engineers
- State – emergency services, geological surveys, boating/waterways
- Local – emergency management, police/fire, lifeguard, park rangers
- Academic – researchers, engineering, modeling
- Non-government – ports, harbors, marinas, business
- Individuals – ship captains, private boater owners

Guidance is also provided to improve the safety of individual boat captains and boat owners**. It is essential that agencies and individuals in each 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 implement 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.

Objective and Scope of the Guidelines

There are a number of goals of this guidance:

- 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 facilitate and encourage emergency management, overall maritime, and individual harbor response planning activities;
- To depict the area(s) affected by and safe from a tsunami;
- To create viable maps through a thorough assessment of local risks.

These guidelines are divided into several sections based on the needs of the product developers and users. The various NTHMP subcommittees are responsible for developing and monitoring the use of these different portions of the guidance:

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

The following section documents the first of these three planned guidance documents. It covers aspects of tsunami hazard analysis, and associated modeling and map products which demonstrate the tsunami threat for maritime communities.

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Tsunami Hazard Analysis, Modeling, and Mapping Guidelines

The foundation for these guidelines are the outcome of the 2012, 2013, and 2014 NTHMP Summer Tsunami Workshops, and were developed and 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 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. These demonstration projects have provided valuable analysis and practical solutions. Where appropriate, these demonstration projects will be 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 must be well understood. The following are examples of tsunami hazards and potential damage related to those hazards:

- Sudden water-level fluctuations
    - Where boats and docks 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 openings/parts of harbor
- Tsunami bores and amplified waves resulting in swamping of boats and damage to docks
- Eddies/whirlpools causing boats to lose control
- Drag forces on large keeled boats causing damaging forces to boats tied to docks
- Collision with other boats, docks, and debris in the water
- Long duration of dangerous tsunami conditions which can 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

Use of Numerical Tsunami Models and Digital Elevation Models/Grids

The accuracy of numerical modeling of tsunami currents must be first verified prior to use of a particular model platform. NOAA and the NTHMP MMS have verified a suite of numerical model platforms for use to determine tsunami inundation and run-up (NTHMP, 2012), however this has not been completed for tsunami current velocities. This can best be accomplished by comparison to real tsunami velocity data from ADCP, video interpretation, and observations of historical events. The NTHMP is developing a set of benchmarks tests for the validation of modeled tsunami currents. **Once the benchmarks are developed, all entities receiving funding from the NTHMP for this work should demonstrate the validity/accuracy of the numerical model used.** The NTHMP will hold a model validation workshop in February 2015 for benchmarking various models using this set of tests. In lieu of this validation, there are several methods to use to demonstrate that modeled currents are sufficiently accurate:

- With real data - Select several harbors where known strong tsunami currents have been measured, observed, or would be expected. Gather as much information about historical

tsunami currents for these harbors. Model past tsunami event at sufficient resolution (10m or less) and validate the numerical model results against the measured, observed, and historical tsunami currents.

- Without real data – Use a high-order numerical tsunami model with a high-resolution DEM (5m or less) to model several source events of various hazard level. This modeling will form the "ground-truth" to compare to the model and DEM resolution proposed for maritime hazard products.

High-resolution digital elevation models (DEMs) must be used in numerical modeling to adequately capture maritime structures and other important features within harbors/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 modeling data from 30m data is used, modelers should verify the results are suitably accurate based on comparison to 10m data for the location being modeled.

DEMs should be evaluated to make sure they contain the most accurate and up-to-date base bathymetric and topographic elevation data. For most areas of the U.S. coast, the National Geophysical Data Center has produced bathymetric-topographic DEMs of 10m resolution specifically for use by numerical tsunami models. Recent, higher resolution (1m to 2m) Lidar has been collected in many coastal areas and, if possible, this data should be used to update existing DEMs.

Products

Maritime tsunami hazard preparedness products may include maps and plans that are printed, digital files, or interactive/web-based. Based on this information, specific tsunami hazard mapping products are likely most useful to maritime communities:

1) **Areas of past tsunami damage and strong currents**
2) **Current velocities and relationship to damage**
3) **Peak-to-trough water-level fluctuations**
4) **Bores or amplified waves**
5) **Length of time damaging currents are active**
6) **Safe minimum offshore depth for vessels**

These six map products follow as topic headings and will be the focus of the modeling and mapping portion of the guidance. Guidance will be provided for both the "development" and "use" for 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 are also a good product to help visualize in hazard analyses, and educate the harbor personnel and public about the impacts of these hazards.

1) 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 Geophysical Data Center 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

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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.

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. 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 the Appendix.

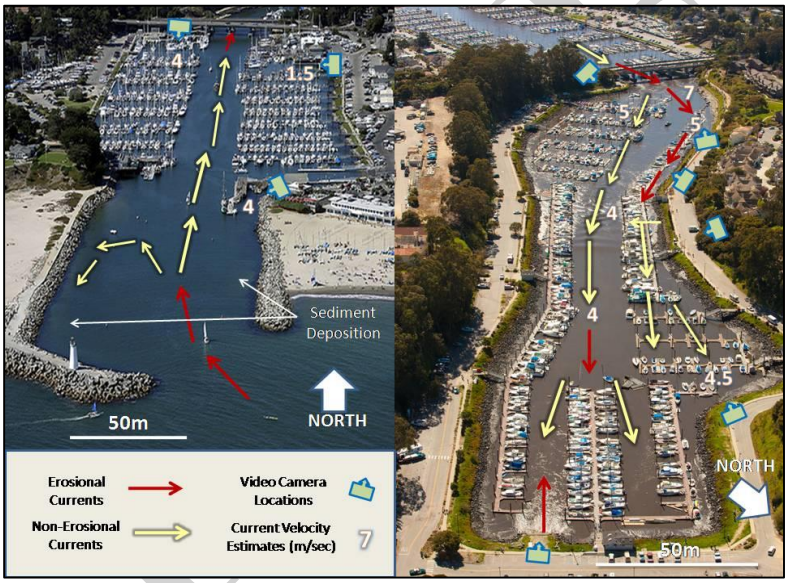

Figure 1 Location of strong and erosional currents inside Santa Cruz Harbor during the 2011 Japan tsunami (from Wilson and others, 2012a).

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

2) Current Velocities and Relationship to Damage

Most tsunami damage inside harbors can be directly attributed to strong and unpredictable currents. Maps identifying these 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 harbors. Prior to development of current velocity maps, numerical models should be verified against the NTHMP benchmark tests and/or comparison to observed tsunami currents from historical events.

Product Guidance

Once the numerical model platform is verified to be accurate, the following guidance for modeling and resulting map production should be followed:

1) Select a suite of tsunami scenarios to model. These scenarios can include historical events, but synthetic scenarios should represent a range of sizes so that they can be utilized for planning harbor response for future events. Sources could represent various events that would trigger

Advisory-level alerts and small, medium, and large Warning-level alerts. 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 of 10m in harbors with a closed entrance, or 30m in harbors with an open entrance or large structures exist; if used, 30m modeled data should be verified against 10m data. If significant differences exist between the results of the two resolutions, use the higher resolution results. 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 data 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 and others (2013) determined that although damage in harbors might vary based on the age and location of docks and boats, some generalities about the relationship between tsunami currents and damage can be determined. As expected, Figure 2 shows a general trend of increasing damage with increasing current speed. In this data, there is a noticeable threshold for damage initiation at ~3 knots [1.5 m/s]. When 3 knots is exceeded, the predicted damage state switches from no-damage to minor-to-moderate damage. 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 major. 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 indicates 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 to use for older (>40-50 years old) and less maintained docks (Pat Lynett, personal communication).

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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

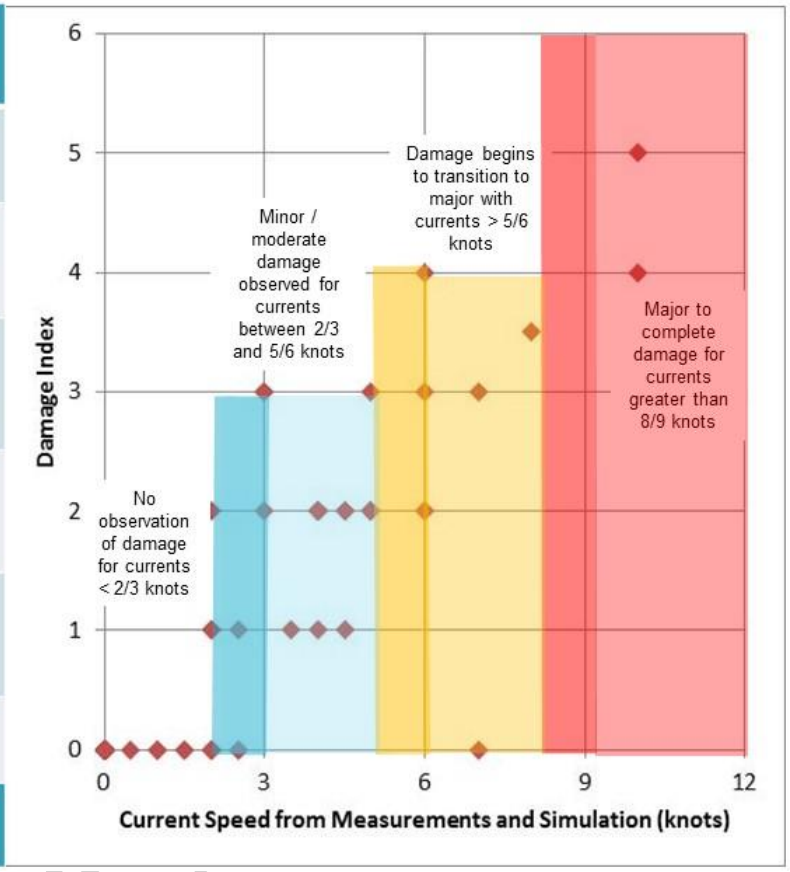

Figure 2 Graphic showing the relationship between strong tsunami currents and damage in a number of harbors and real events. The red points represent damage-current data from past events and tsunami modeling (modified from Lynett and others, 2013). ****NOTE: We are still working on determining the best colors for these products/maps.**

As shown in Figure 3, these 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 all be combined onto one single map to demonstrate what the "worst case" conditions might be throughout the harbor. 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.

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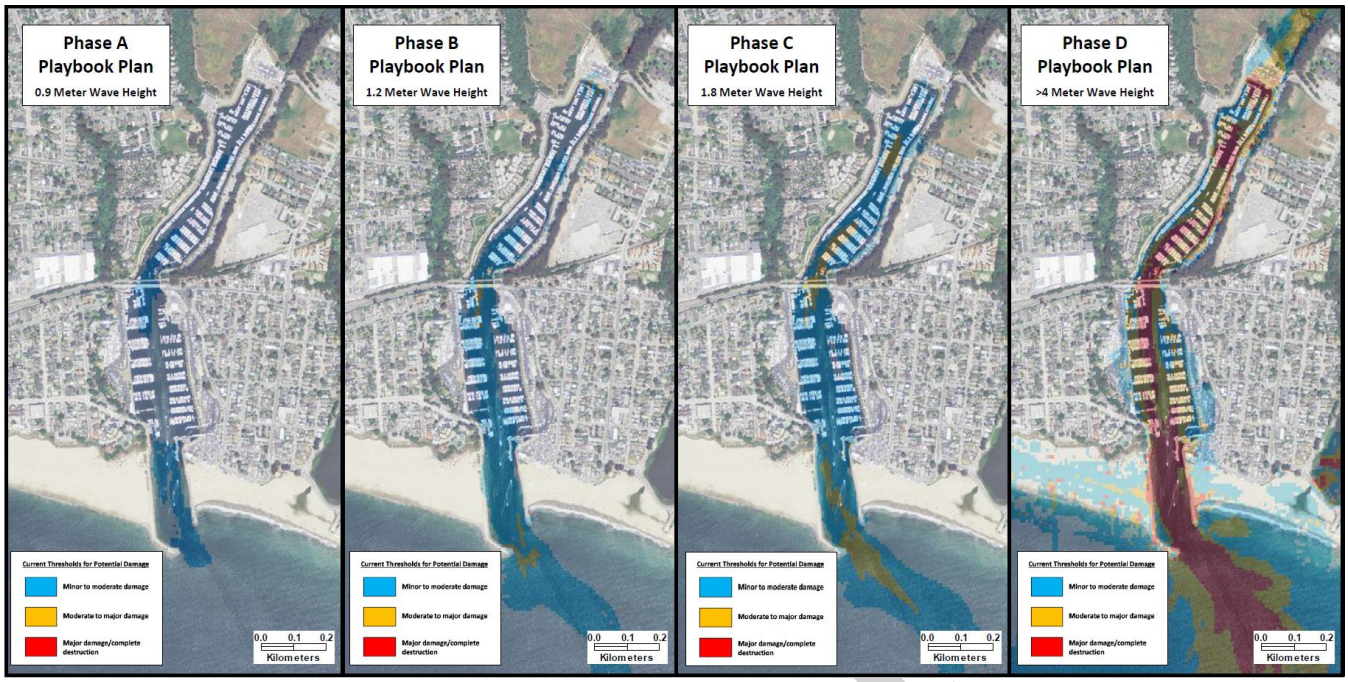

Figure 3 Example maps from Santa Cruz Harbor showing potential damage based on strong currents generated by a tsunamis of different amplitudes (Tsunami Planning Playbook for Santa Cruz Harbor, 2014). *****NOTE: We are still working on the best colors for use in these products/maps.***

3) Peak-to-Trough Water-level Fluctuations

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 directly damaged on the bottom or become stuck in muddy sediment or debris on the bottom. Vessels moored to docks and piers can torque and break mooring lines and/or collide with the docks and cause damage. Boats can also float onto the top of docks and piers and docks can also overtop piles if water levels rise suddenly. And, although moving ships during a tsunami is not recommended, large drops in water level could create very shallow conditions in navigation channels. Utilizing tsunami flow depths from real-time model results or from the FASTER approach, which incorporates forecast amplitudes, storm and tidal conditions, errors in the modeling, and run-up potential (Wilson and others, in press), can help indicate how high the water will get within the harbor and if docks will overtop piles (see the appendix for more information about FASTER approach). *****NOTE: Rick Wilson will provide visuals/figures to show how these products would look.*****

Product Guidance

Maps can be created that identify the amount of total water level change as well as the highest and lowest water level related to a set elevation or (tidal) datum. The following steps should be followed to produce tsunami hazard maps identifying areas of large water fluctuation, peak and trough elevations, and where shallow harbor conditions might occur during an event:

1) Utilize the modeled time history results from large scenarios to develop a map that shows the difference between the maximum peak and trough amplitudes through the harbor.

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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 Low Low Water datum will provide the "worst case" for exposed areas.
3) The modeled maximum flow depth added to the Mean High High Water datum can be used to identify how high water can get. This can be compared to the elevations of the permanent piers and docks to see where ships might overtop them. Again, make sure all comparisons are based on the same vertical/tidal datum or zero elevation.

4) Areas of Potential Bores and Amplified Waves

Unique tsunami conditions, such as bores and amplified waves, can cause damage to portions of harbors where wave activity is not commonly seen. Bores typically occur on rivers or up channels where the tsunami gets funneled into narrow area. As was seen during the 2011 tsunami, a number of single, amplified waves 1 meter high was generated and entered into the back part of Santa Cruz Harbor, three hours after first arrival of the tsunami from Japan (Figure 4; Wilson and others, 2012a). These waves caused significant damage to docks and boats.

*****NOTE: Jim Kirby will try develop a write-up for this section*****

Figure 4 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).

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5) Length of Time Damaging Currents Are Active

The duration of strong, damaging tsunami currents is of great importance to harbor masters and emergency managers for their 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 and others (2013) indicated, for numerical models run for a 60 hour tsunami period, although there is little phase correlation between the model and measure data, the envelope of the wave heights and current velocities decay is actually captured. This information can therefore be used to provide a general sense of time of activity for specific strong currents.

To determine the duration of damaging currents, “time-threshold” maps can be generated. 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. While this type of information should be very useful for harbor personnel to estimate the duration of potential impacts, the estimates will be highly source dependent and scenario specific. Figure 5 shows an example of what these maps might look like (Lynett and others, 2013).

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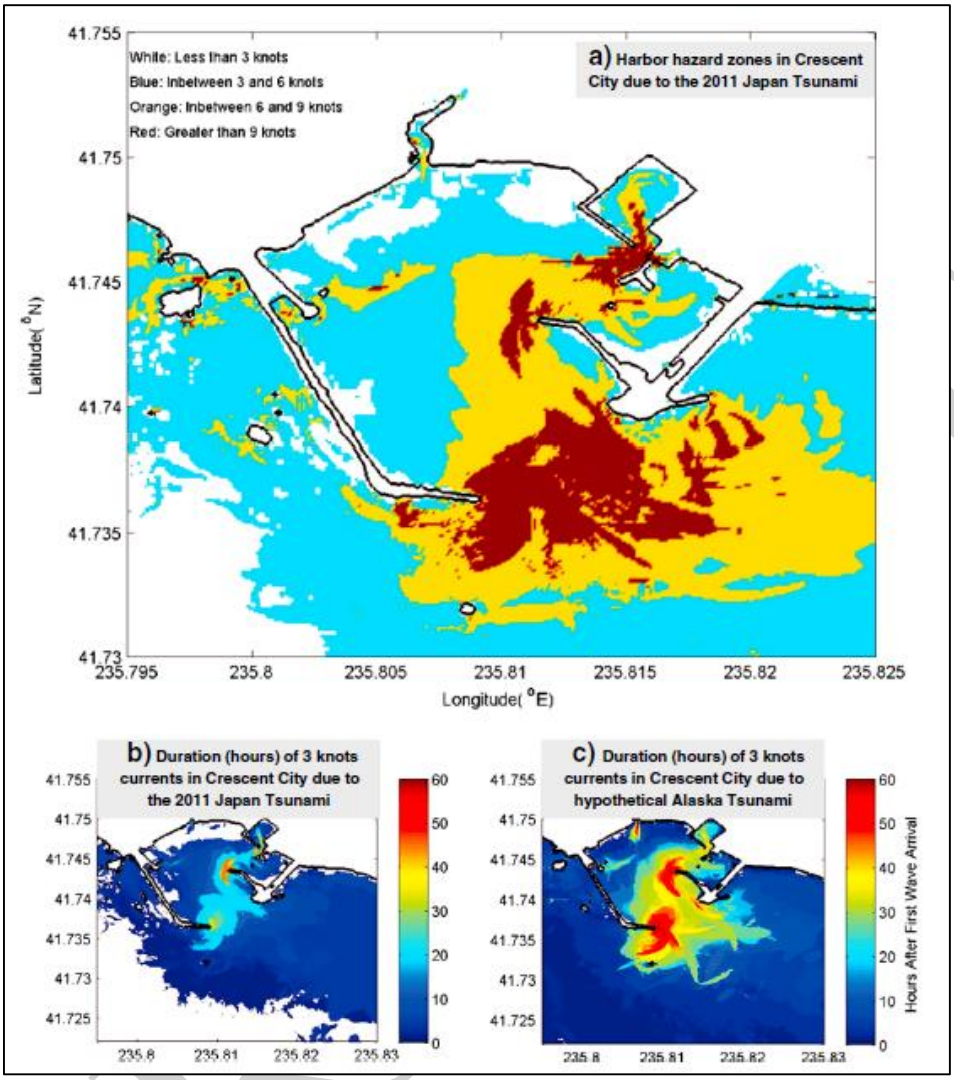

Figure 5 Example uses of the current speed hazard zones for 3/6/9 knot zonation, and time-threshold maps for two different sources in Crescent City Harbor (from Lynett and others, 2013).

Product Guidance

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?) are active.
2) Maps can be created that show the same time-threshold for multiple scenarios (Figure 5), or multiple time-thresholds for the same scenario (Figure 6).
3) When displaying multiple time-thresholds on a maps, the colors used for the times should have a consistent scale for the best comparison.

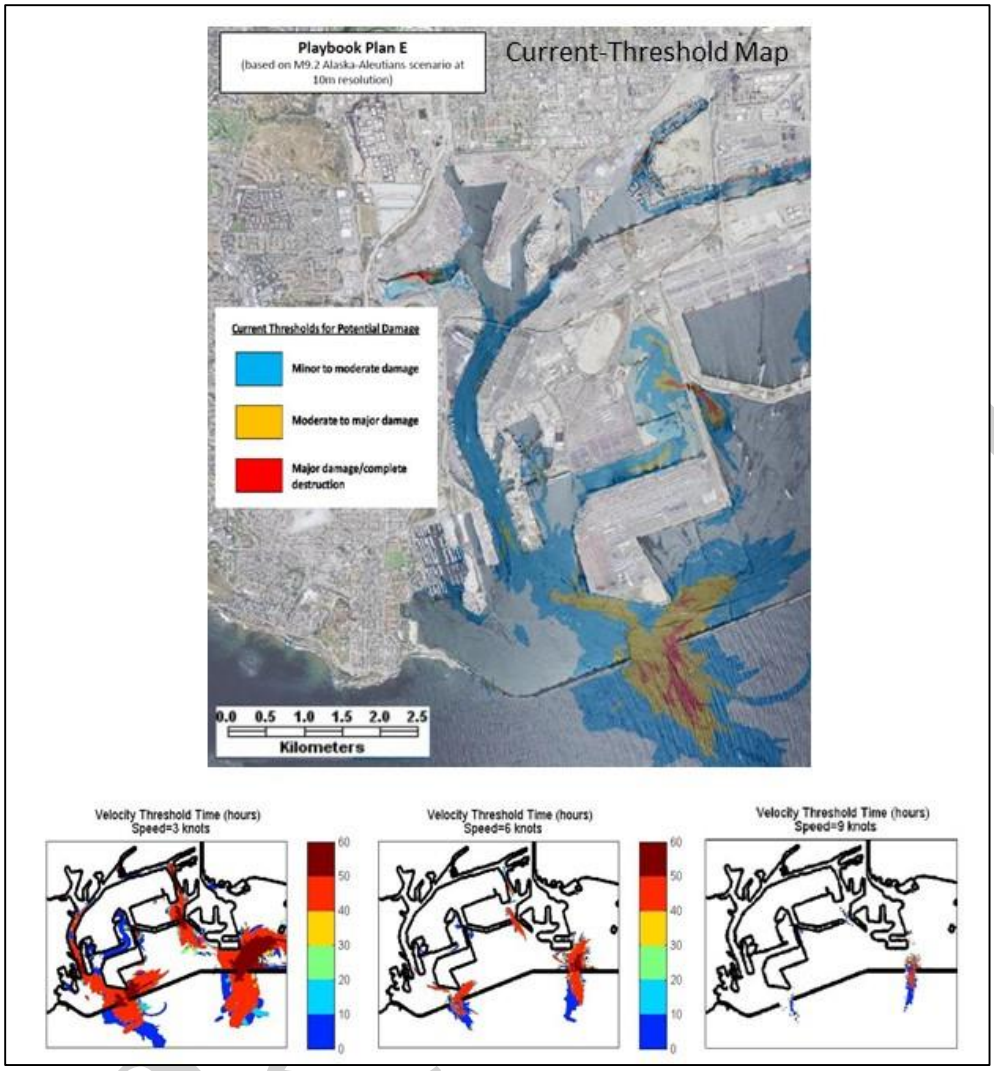

Figure 6 Example of current velocity-damage threshold map (3/6/9 knots), and time-threshold maps for each of the current-damage thresholds in the Port of Los Angeles (from Tsunami Planning Playbook for Port of Los Angeles, 2014).

6) Safe Minimum Offshore Depth

It is always safer for boat owners and captains to NOT be on their boats during a tsunami. However, if mariners are experienced and prepared for staying at sea for up to a 24 hour period, they may try to take their vessel out of harbor and go offshore. In the event of a distant-source tsunami where there is sufficient time to safely move or evacuate vessels from a harbor, or a local-source tsunami where vessels are already at sea, 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. There are a number of conditions which should be met for a depth be recommended as “safe”, such as no chance of vessel grounding, negligible wave steepness, and readily navigable currents. From observations of tsunami induced coastal currents in

previous events, the challenges to coastal navigation are due to both strong currents and rapidly changing currents, 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 toward sea at all.

The general recommendation from NOAA is to travel to the 100 fathom (600 foot) depth, which is considered overly conservative and unrealistic to travel to along some coastlines. Recent analyses in California and Oregon indicate that a 30 fathom (180 foot) depth can be used along the Pacific coast of North America during distant source events (Lynett and others, 2013; Oregon Marine Advisory Committee, 2014). The California analysis included a scatter plot of maximum currents versus water depth (Figure 7). It 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 with the same results. The California Tsunami Steering Committee has accepted that depths greater than 30 fathoms will be safe, particularly for dispersed or larger vessels.

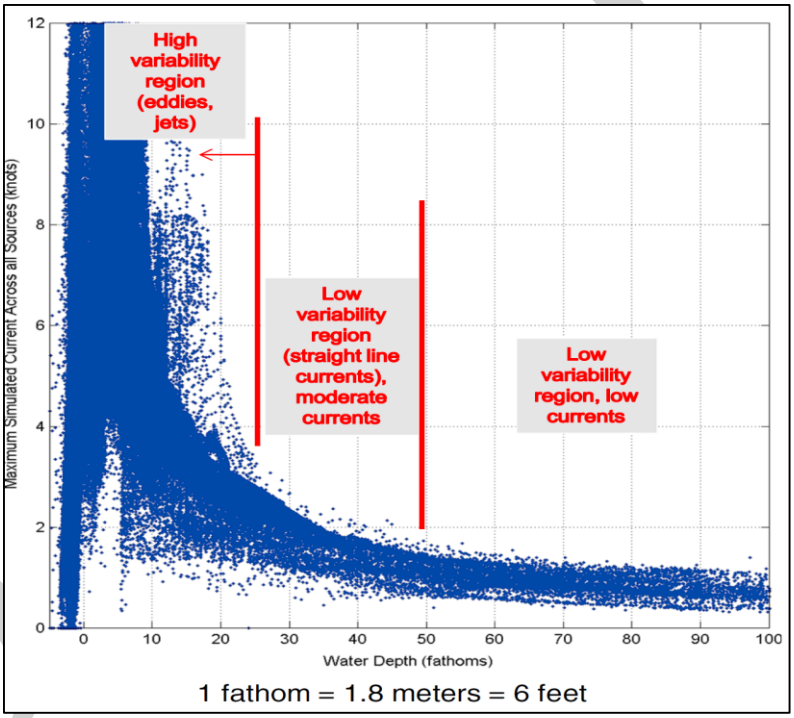

Figure 7 Scatter plot of maximum modeled current velocity versus water depth at Crescent City Harbor (Lynett and others, 2013).

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) in map view (Figure 8). Current velocities less than 3 knots were considered ideal for a safe depth. The potential for offshore vortices were also analyzed. Oregon determined that the safe depth for distant source events should be 30 fathoms, but vessels at sea during a local Cascadia source event should head to a depth of 100 fathoms to be safe.

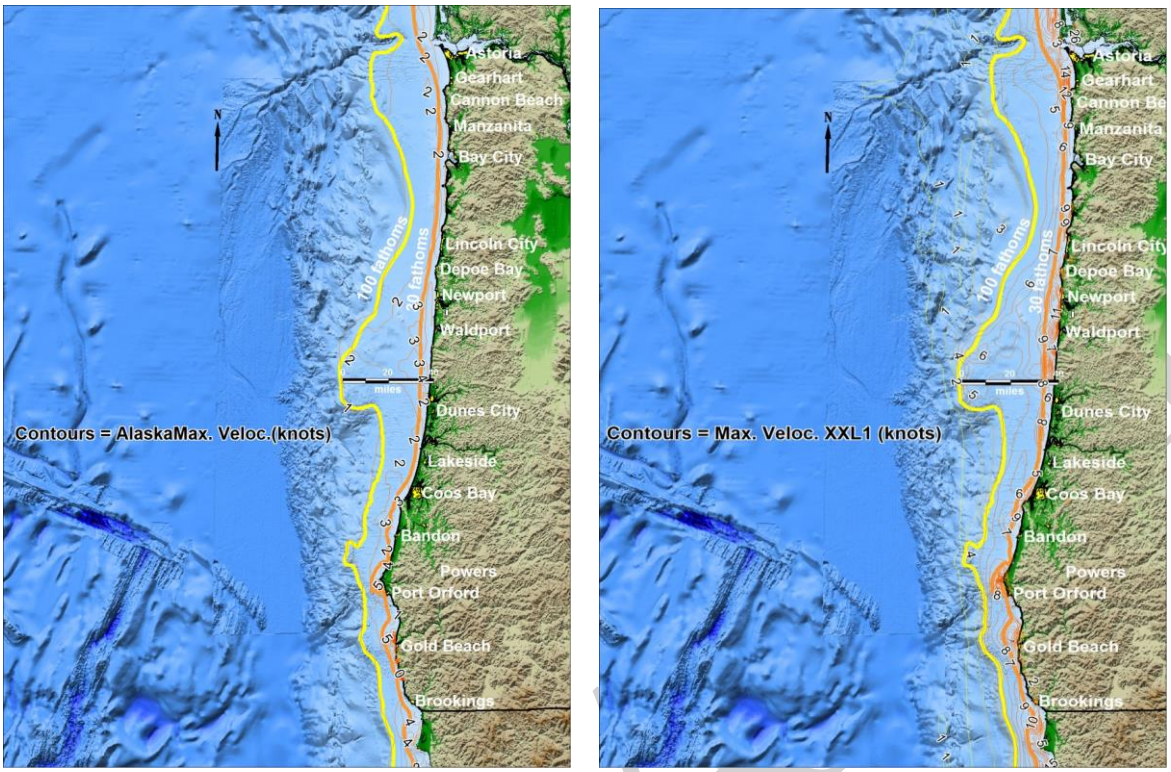

Figure 8 Maximum tsunami current maps for a modeled large Alaska scenario and a large Cascadia scenario (Oregon MAC, 2013).

Maritime evacuation maps can be created using 30 fathoms and 100 fathom lines. In addition, more detailed and controlled vessel evacuation plans are recommended for harbors. For example, the U.S. Coast Guard have developed a maritime evacuation plan for some harbors and ports in Hawaii. Figure 9 is an example of what these plans might look like. 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 the evacuation.

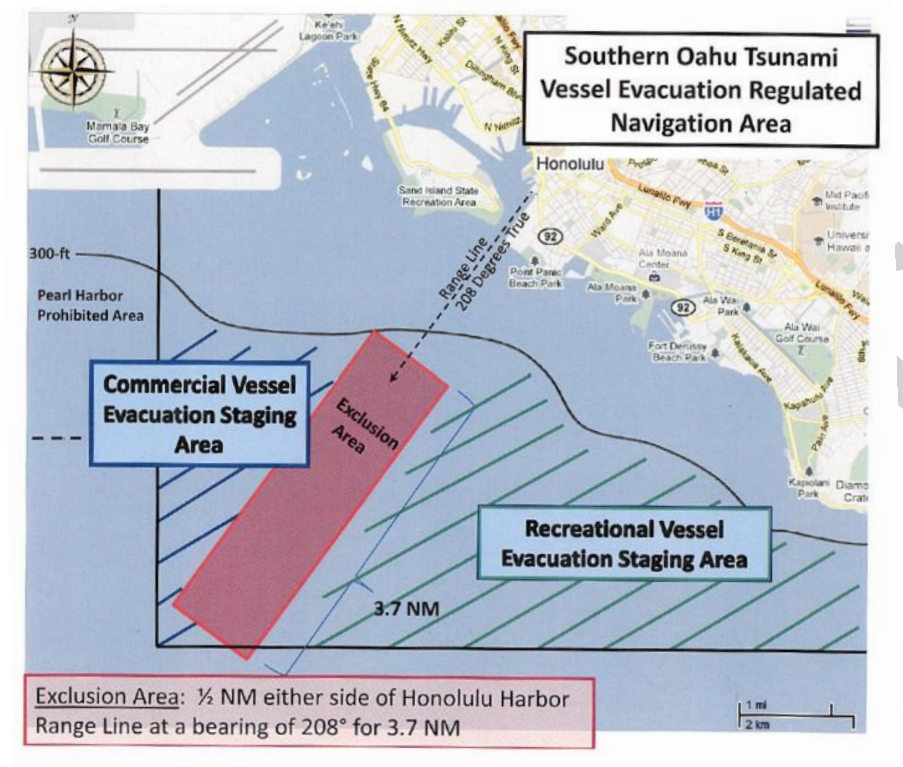

Figure 9 Map showing maritime evacuation plan for vessels in the port at southern Oahu (from Coast Guard, 2013).

****NOTE: Other states and territories will be evaluating the offshore safe depth and presenting results at the February 2015 NTHMP meeting****

Other Potential Tsunami Hazard Maps and 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. Nonetheless, they should be discussed:

- Sediment Movement – Evaluation of sediment movement during a large tsunami can help harbors determine if mitigation measures such as sediment control structures or additional dredging might be needed. Dredging of sediment in a post-tsunami environment could be costly because of the high potential for sediment contamination. Wilson and others (2012b) evaluated sediment movement within Crescent City and Santa Cruz harbors during the 2011 Japan tsunami (Figure 10). 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 impact from background erosion/sedimentation in the harbor. It is also important to make sure that all

bathymetric data sets are set to or corrected to a common datum. Cross sections from the bathymetry and sediment cores can also be a useful product for harbor recovery planning.

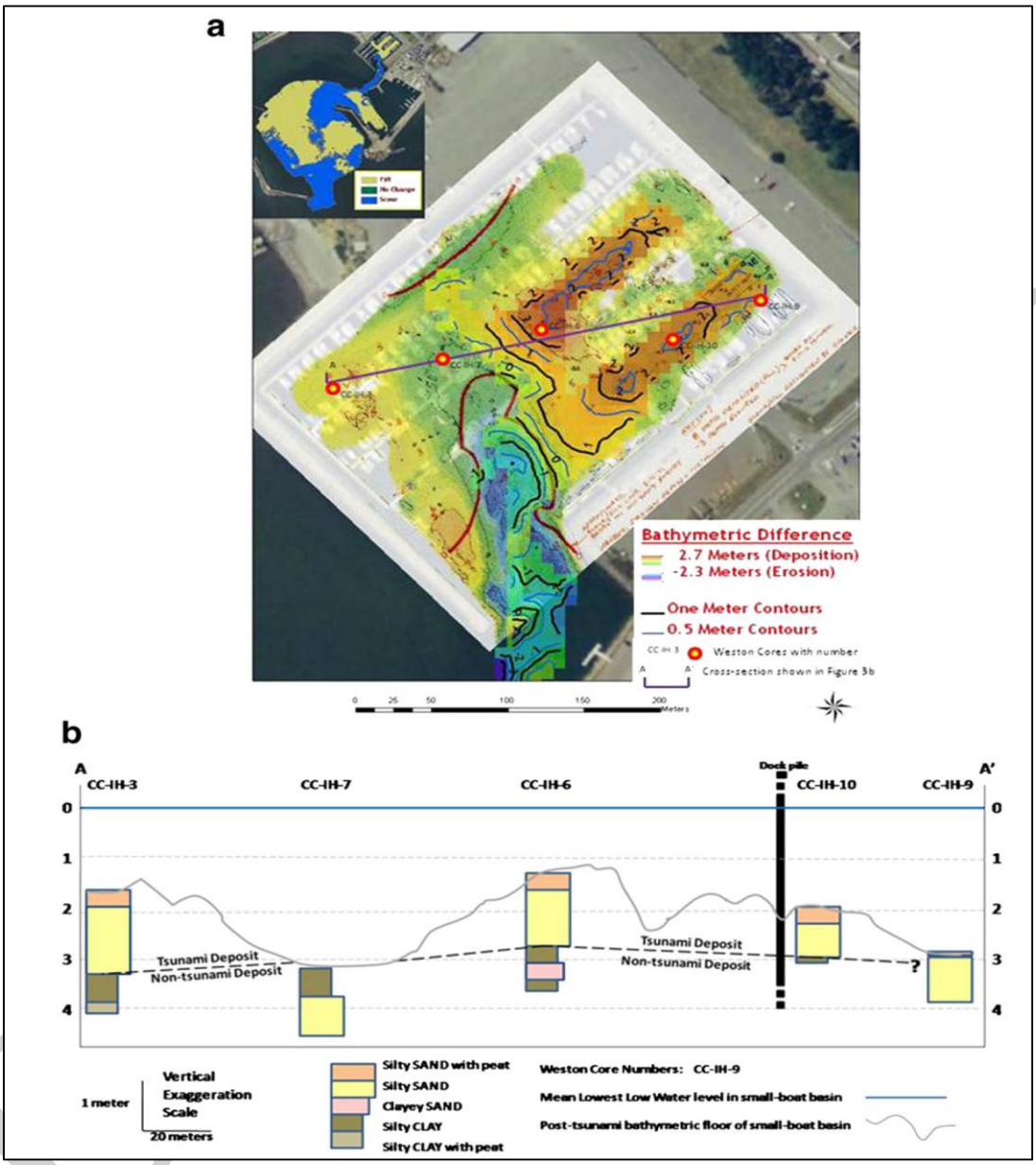

Figure 10 Areas of scour and fill in the Crescent City Harbor Small-Boat Basin determined by differencing multi-beam bathymetric data. The cross section shows the post-tsunami sediment composition and correlation between tsunami and non-tsunami deposits (from Wilson and others, 2013b).

- Debris Movement Models – Although ships and docks may seem safe from direct damage from strong tsunami currents or water-level fluctuations during certain events, loose debris can 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 to. Lynett (unpublished) is developing a debris model that is based on simple particle movement within his current models. Figure 11 shows a screen shot from a debris/particle movement model in the Port of Los Angeles. This time-history movie showing potential debris movement 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 in and out of the Port.

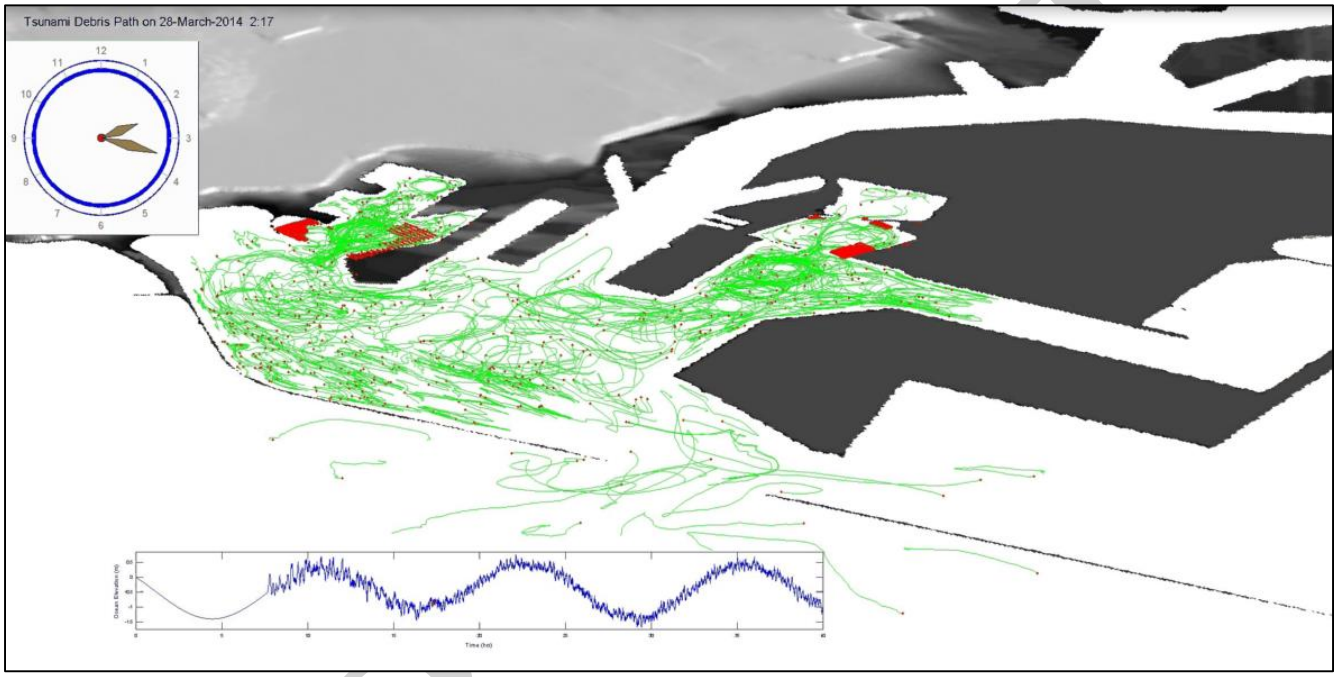

Figure 11 Modeled debris/particle movement from small-boat basins within the Port of Los Angeles (Lynett, unpublished).

- Mitigation Analysis and Products – Many harbor managers are interested in understanding the vulnerability of their harbor facilities and infrastructure to tsunami damage. More detailed information on where and what type of harbor structures might need improving will help these harbors apply for Local Hazard Mitigation Grant funding. 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, Lynett and Eskijian (unpublished) 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 12). These types of analyses will help harbors pin-point where dock and infrastructure improvements could be implemented. How these products can be incorporated into hazard mitigation planning will be discussed in a later section of the guidance.

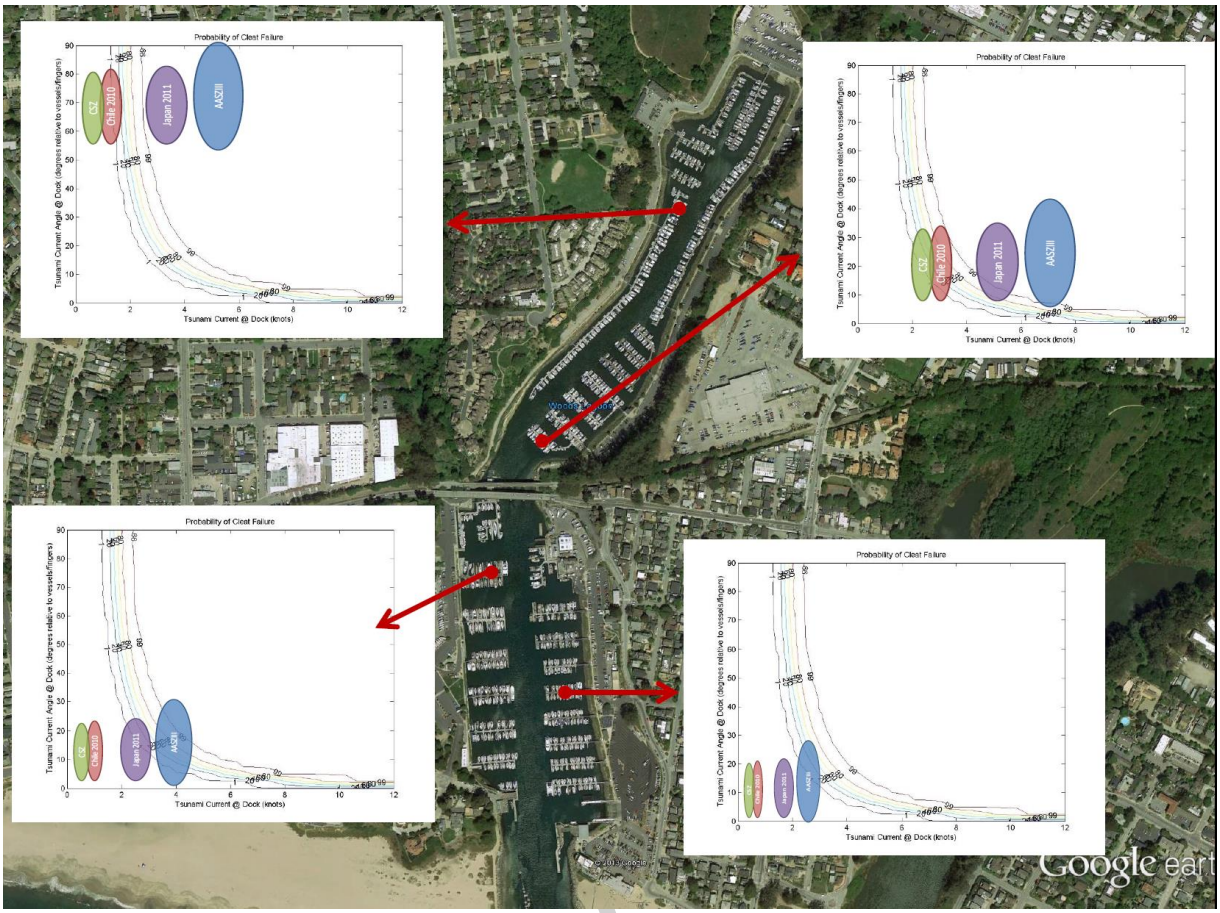

Figure 12 Failure probability curves for cleats in Santa Cruz Harbor. The current speed and direction for various modeled scenarios have been added to the curves for reference, to help determine what portions of the harbor might be most vulnerable.

Basic Mapping Guidance and Content

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

- All maps and products must include a title, scale, geographic location (coordinates), intended use, and appropriate explanatory information.
- All maps and products must reference technical documentation on how the map was made and its intended use.
- Maps must 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 must be legible for all users, including people with color vision disabilities.

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- 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.
- Bilingual where applicable, with English and another language
- Brief 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 13 Standardized mapping symbols

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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 you choose not to use the colors suggested below, make every effort to ensure that the publication is readable by the color blind
    - Avoid putting the color red next to the dark green color.
- 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 14 Suggested standardized colors for tsunami hazard maps and products.

Guidance for Tsunami Response, Preparedness, and Education:

NOTE: Although the NTHMP has not yet developed specific guidance for tsunami response, preparedness, and education, a number of resources exist for states, territories, and communities to use. Recommended actions have been developed by Puerto Rico, Hawaii, California, and Oregon. The Japanese have also developed similar types of recommended actions for harbors and the boating community. Harbor specific response plans, or maritime tsunami response "playbooks," have been developed for harbors and ports in California; see the Appendix for an example of one of these playbooks. Examples of guidance from other resources are summarized here and referenced in the references section:

From the Oregon Division 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

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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.

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- 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

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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)

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

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., in press, Tsunami emergency response playbooks and FASTER tsunami height calculation: Background information and guidance for use: California Geological Survey Special Report.

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APPENDIX – Example of a Maritime Tsunami Response Playbook (California)

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California Maritime Tsunami Response Playbook And Mitigation Guidance

Port of Los Angeles – Los Angeles County

Maritime Tsunami Response Playbook (MTRP) No. 2014-LA-01

DURING AN EMERGENCY, USE THE "QUICK REFERENCE" SHEET ON THE BACK PAGE (PAGE 22).

(For the expanded Playbook format, use directions on page 7)

California Maritime Tsunami Response Playbook No. 2014-LA-01

California Geological Survey
California Governor's Office of Emergency Services
University of Southern California
Humboldt State University
National Oceanic and Atmospheric Administration

Funded by the Federal Emergency Management Agency and the National Tsunami Hazard Mitigation Program

Table of Contents – Tsunami Response Plan Playbooks

Page 2: Purpose and Use of Maritime Response Tsunami Playbook and Mitigation Guidance
Page 3: Mitigation Planning
Page 4-5: Tsunami Hazards, Tsunami Alert Levels, and General Response Recommendations
Page 6: Forecast Amplitude and FASTER Reference Information; Current-Damage Relationship
Page 7: Expanded Response Reference Page
Pages 8-17: Maritime Tsunami Response Playbook Scenario Plans and Maps
Page 18-19: Notable historical tsunamis and state tsunami program modeling results
Page 20-21: Offshore and On-shore Evacuation Plans
Page 22: APPENDIX – QUICK REFERENCE PAGE For Real-Time Maritime Response Activities

DURING AN EMERGENCY, USE THE "QUICK REFERENCE" ON PAGE 22 FOR GATHERING INFORMATION FOR RESPONSE ACTIVITIES.

PURPOSE: This Maritime Tsunami Response Playbook Guidance document will help members of the maritime community prepare, plan, and respond to strong currents and damage from future tsunamis. It has been developed with assistance from the Port by the California Tsunami Program and principle funding from FEMA. **It is essential that harbor staff become familiar with this Playbook guidance document before use.** The information within the Playbook can also help the harbor develop and implement tsunami mitigation strategies through their Local Hazard Mitigation Plan, and receive potential mitigation funding if needed.

USE: This Playbook is primarily designed to help the Port with tsunami response activities by providing detailed information about potential tsunami scenarios which can be used during an event.

First, it requires that the **harbor develop response plans for each of the scenarios in the Playbook;** this should be done when the Playbook is first received. The California Tsunami Program will work with the Port to assist in develop these plans if requested.

When a tsunami is occurring, follow the steps outlined in either the Quick Reference guideline on the last page (Page 22) if the user is not as familiar with the Playbooks, or the Expanded Reference guideline on Page 7 if the user wants more detailed information. The harbor master or emergency response manager should **fill out information about the source earthquake and tsunami;** this information can be obtained from multiple sources, including the tsunami alert message from the National Tsunami Warning Center (NTWC) in Alaska, the city or county emergency manager, and/or the National Weather Service, Regional Weather Forecast Office. Keep in mind that this information can change during the first hour or two after the earthquake occurs.

Finally, **compare the tsunami forecast amplitude (wave height) to the maximum tsunami amplitude on the scenario table on Page 7 or 22**. Choose the scenario (Pages 8-17) which best matches the forecast information. Follow the instructions on the page for that scenario. Each scenario Playbook may be accompanied by a digital file indicating the response and evacuation plans; this can be shared during an emergency with emergency responders in the field.

MITIGATION PLANNING

In addition to using these Playbooks for tsunami response, the California Tsunami Program, FEMA, and its partners encourages maritime communities to utilize this information to help mitigate damages and loss of life from future tsunamis. These products and plans should be used by maritime communities to identify real-time response mitigation measures, determine where infrastructure enhancements should be initiated, 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 California maritime communities. Therefore, we recommend the following steps/actions:

1. **Review the maps within this Playbook guidance document to identify where strong currents 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 state tsunami program, 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 mitigation measures	Permanent mitigation measures
Moving boats and ships out of harbors	Fortify and armor breakwaters
Repositioning ships within harbor	Increase size and stability of dock piles
Move large, deep keeled ships from harbor entrance	Strengthen cleats and single-point moorings
Remove small boats/assets from water	Improve floatation 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	Debris deflection booms to protect docks
Alert key first responders at local level	Harbor control structures being tsunami resistant
Restrict traffic entering harbor; aid traffic evacuating	Construct breakwaters further away from harbor
Personnel to assist rescue, survey and salvage	Install Tsunami Warning Signs
Identify boat owners/live-aboards; establish phone tree, or other notification process	Equipment/assets (patrol/tug/fire boats, cranes, etc.) to assist response activities

There are a number of **TSUNAMI HAZARDS** that could directly affect boats/boaters:

- Sudden water-level fluctuations
  - Where boats and docks 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 openings/parts of harbor
- Tsunami bores and amplified waves resulting in swamping of boats and damage to docks
- Eddies/whirlpools causing boats to lose control
- Drag on large keeled boats causing damaging forces to boats tied to docks
- Collision with other boats, docks, and debris in the water
- Dangerous tsunami conditions can last tens of hours after first wave arrival, causing problems for inexperienced and unprepared boaters who take their boats offshore

Tsunami Alert Bulletins: During the typical tsunami alert, the Warning Center provides information about the tsunami in "bulletins" to the state and local jurisdictions. There are four levels of "alert" that can be sent by the NTWC (from least to greatest significance; http://ntwc.arh.noaa.gov/):

Tsunami Information Statement - Issued to inform and update emergency managers and the public that an earthquake has occurred, or that a tsunami Watch, Advisory or Warning has been issued elsewhere in the ocean.

Tsunami Watch - Issued to alert emergency managers and the public of an event which may later impact the Watch area. May be upgraded to an Advisory or Warning - or canceled - based on updated information and analysis.

Tsunami Advisory - Issued due to the threat of a tsunami which may produce strong currents or waves dangerous to those in or near the water; typically called when forecasted tsunami amplitudes are between 0.3m and 1m (1ft and 3ft) above existing tidal conditions are expected. Coastal communities are advised that beach and harbor areas could expect rapid, moderate tidal changes and strong currents.

Tsunami Warning - Issued when a tsunami with significant widespread inundation is imminent or expected; typically called when forecasted tsunami amplitudes are equal to or greater than 1m (3ft). Coastal communities are advised to evacuate people from low-lying areas identified as vulnerable to tsunamis.

ACTIONABLE TSUNAMI ALERT LEVELS

Tsunami Advisories and Warnings are the two actionable Alert levels for maritime communities.

Actions taken will depend on the Alert level and the forecasted tsunami wave height or amplitude for a particular harbor. For both Advisory and Warning level events, it is important that clear and consistent directions are provided to the entire boating community and waterfront businesses.

If there is not sufficient time to use the Playbooks, consider the following general actions for your maritime communities for either Advisory or Warning level events:

GENERAL "WARNING" LEVEL RECOMMENDATIONS

All activities below should be completed no later than one hour before forecasted tsunami arrival.

- Evacuate the public and harbor personnel from all structures and vessels in the water, as well as all land-ward areas identified in the mapped tsunami evacuation area (last page).
- Advise facility maintenance to shut off fuel to fuel docks, and all electrical and water services to all docks.
- Secure and strengthen all mooring lines throughout harbor, specifically areas near the entrance or narrow constrictions.
- Do not allow public to re-enter tsunami evacuation area until Warning is downgraded or cancelled.
- Follow instructions for an Advisory if Warning is downgraded to Advisory level.

GENERAL "ADVISORY" LEVEL RECOMMENDATIONS

All activities below should be completed no later than one hour before forecasted tsunami arrival.

- Evacuate the public from all structures and vessels in the water.
- Coordinate with local law enforcement to limit access of public along waterfront areas.
- All personnel working on or near the water should wear personal flotation devices.
- Advise facility maintenance to shut off fuel to fuel docks, and all electrical and water services to all docks.
- Secure and strengthen all mooring lines throughout harbor, specifically areas near the entrance or narrow constrictions.
- Do not allow public to re-enter structures and vessels in the water until Advisory is cancelled.

DIFFERENCE BETWEEN FORECAST TSUNAMI AMPLITUDE/WAVE HEIGHT AND FASTER TSUNAMI FLOOD HEIGHT

Forecast Tsunami Amplitude/Wave Height: Within the first couple hours after an earthquake and the generation of a tsunami, the National Tsunami Warning Center will provide an estimate, or forecast, of the potential amplitude/wave height of the tsunami for over 50 locations along the California coast. This amplitude is the height of the tsunami above existing ocean conditions and helps determine the official Tsunami Alert level for each region. **For the purposes of the Playbook, the forecast tsunami amplitude is used on the "Response Reference" page 7 or 22 to determine if piles will be overtopped and inundation of dry land will occur.**

FASTER Analytical Tool: To determine the full impact of tsunami inundation, other variables such as tidal and storm conditions must be considered. An analytical method has been created which incorporates important variables that will impact the ultimate tsunami flood level. The simplified components of the calculation are shown to the right. **The FASTER calculation, which will be provided by the local jurisdiction or the regional NOAA NWS Weather Forecast Office to the harbor during a tsunami event, is used on Page 7 to determine if piles will be overtopped and inundation of dry land will occur.**

Working example: Formula for determining playbook evacuation line to use (FA-S-T-E-R):

FA: **Forecasted Amplitude (Wave Height)** from Warning Center

+

S: **Storm** surge or existing ocean conditions

+

T: Maximum **tidal** height (first 5 hours of tsunami)

+

E: Forecast **error** potential (30%; analysis of 2010-11 events)

+

R: Site amplified **run-up** potential (from existing modeling, unique to each location; applied if inundation expected)

= **Maximum tsunami run-up height**

= **Playbook elevation line**

RELATIONSHIP BETWEEN TSUNAMI CURRENT SPEED AND HARBOR DAMAGE: Analysis of recent tsunami damage indicates a relationship between current speed and harbor damage. The Damage Index to the right has been used in the analysis to determine the following relationship (see color codes here and on maps):

CURRENTS = DAMAGE

0-3 knots = No Damage
3-6 knots = Minor/Moderate Damage
6-9 knots = Moderate/Major Damage
>9 knots = Major/Complete Damage

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

Expanded Reference Information for Determining Real-Time Maritime Response Activities

NOTE: It is important to review all sections of this Playbook prior to using it during a tsunami emergency. When a tsunami alert is issued by the National Tsunami Warning Center, fill out the Expanded Reference page below under Step 1. The state/NOAA will provide information on recommended "Phase" evacuation and response plans to use based on the FASTER tsunami flood level value calculated for each community.

Step 1: Obtain information about earthquake and tsunami from National Tsunami Warning Center in Alaska, regional NOAA-Weather Forecast Office, and/or county and state emergency managers. (e.g. www.tsunami.gov)

Earthquake location _____

Earthquake magnitude _____

Tsunami Alert level (circle one) WATCH ADVISORY WARNING

Forecasted tsunami amplitude/wave height _____ (this will be compared with Peak Amplitude in Step 2)

Forecasted tsunami arrival time _____

Calculate/obtain FASTER tsunami run-up value in first 5 hours: _____

Calculate/obtain FASTER tsunami run-up value at highest tide _____

Height of shortest pilings above Mean Sea Level: _____

Elevation of lowest land above Mean Sea Level: _____

Compare FASTER value to pile heights and lowest land to determine if they will be overtopped.

Step 2:: Compare and match forecasted tsunami amplitude/wave height in Step 1 to "Peak Amplitude" in the table below (red box). Refer to associated Playbook page to determine actions for securing vessels and/or repositioning ships away from areas of expected damage to safe areas within the harbor or offshore (Pg. 20).

Reference Pages for Details in Maritime Playbook	Scenario Playbook Plan Letter	Historical Events and Modeled Scenarios	Earthquake Magnitude and Source Location	Peak Amp. (in meters, above existing conditions)	Likely Tsunami Alert level	Tidal condition (during first 5hrs)	Peak Velocity from Modeling (in knots)	Damage Summary
	(No action)	2009	8.0 Samoa	0.2	Advisory	High	>3	No currents or damage
Page 8-9	A	2011	9.0 Japan	0.5	Advisory	Low	5	Minor damage to docks and boats
Page 10-11	B	2010	8.8 Chile	0.6	Advisory	Low	5	Minor damage to docks and boats
Page 12-13	C	Modeled Scenario	9.0 Cascadia	0.8	Advisory-Warning	High	6	
Page 14-15	D	Modeled Scenario	9.4 Chile	1.0	Warning	High	8	
Page 16-17	E	Modeled Scenario	9.2 Aleutians	1.2	Warning	High	>10	

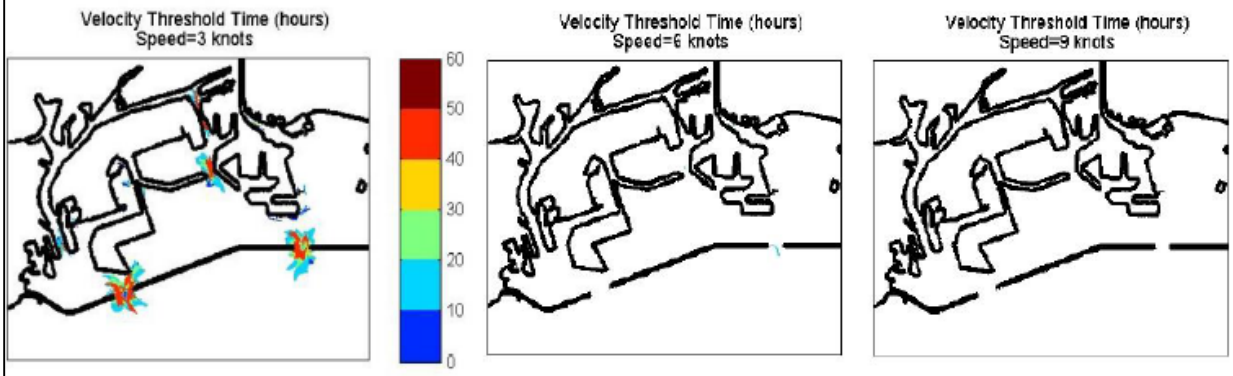
Playbook Plan A
(based on 2011 M9 Japan Event)

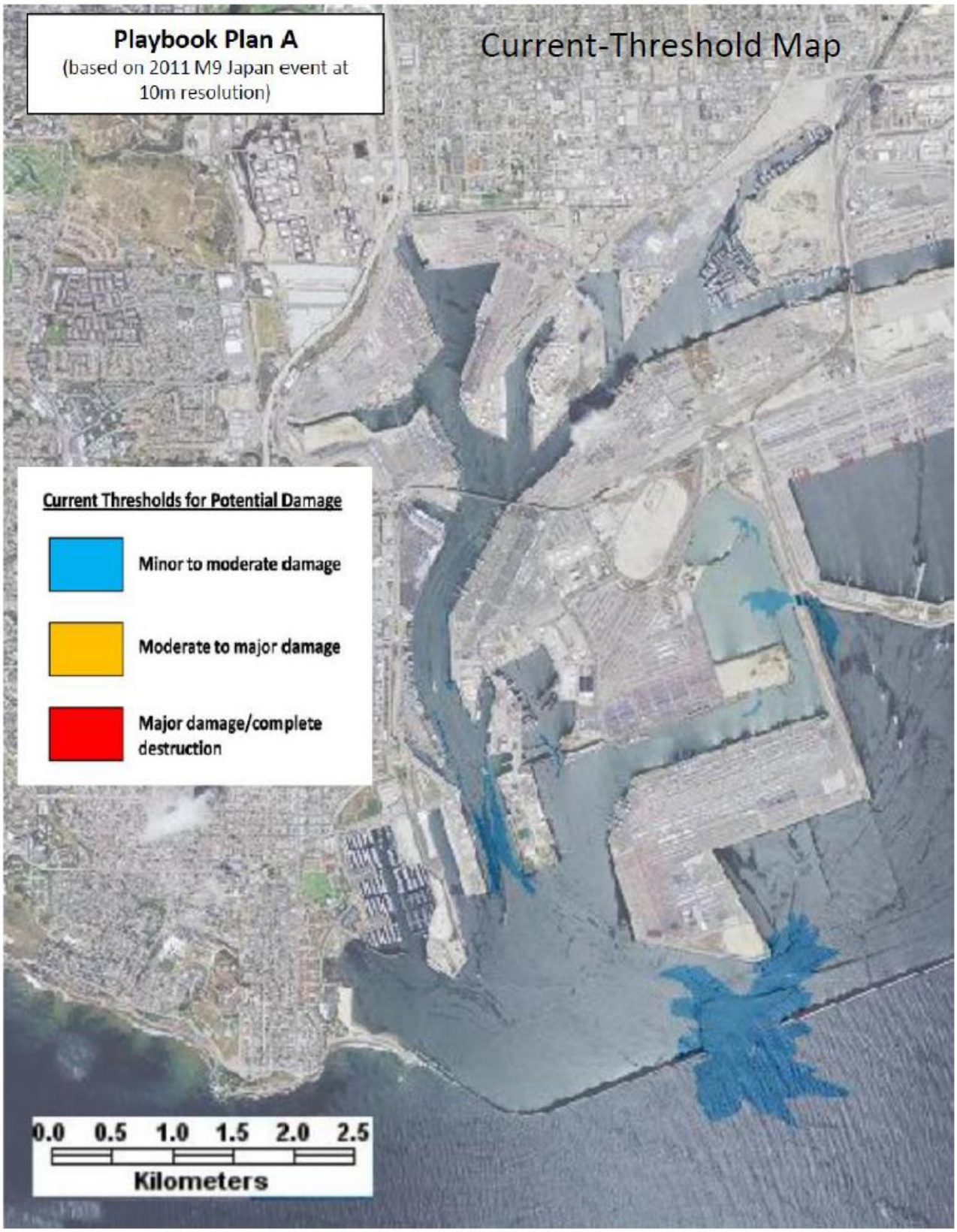
Background Information:
Alert level = Advisory
Peak Amplitude = 0.7 meters (measured)
Peak Velocity = 7 knots
Projected duration of strong currents (see location map below):
3-6 knots = 30 hrs; 6-9 knots = 10 hrs; >9 knots = 0 hrs

Specific Instructions:

- Follow general guidance for Advisory-level tsunamis (Page 5)
- Strong currents and potential scour are expected in areas identified in blue on the map to the right. Consider relocating vessels located within 100 meters (300 feet) of these areas.
- Specific areas where vessels should be relocated and docks secured:
    - Vessels can be moved to non-blue areas of the port.
    - .... (completed with maritime community input)

Safe areas for repositioning vessels within POLA:
..... (completed with maritime community input)




Playbook Plan A
(based on 2011 M9 Japan event at 10m resolution)
Current-Threshold Map
Current Thresholds for Potential Damage
Minor to moderate damage
Moderate to major damage
Major damage/complete destruction
0.0 0.5 1.0 1.5 2.0 2.5
Kilometers

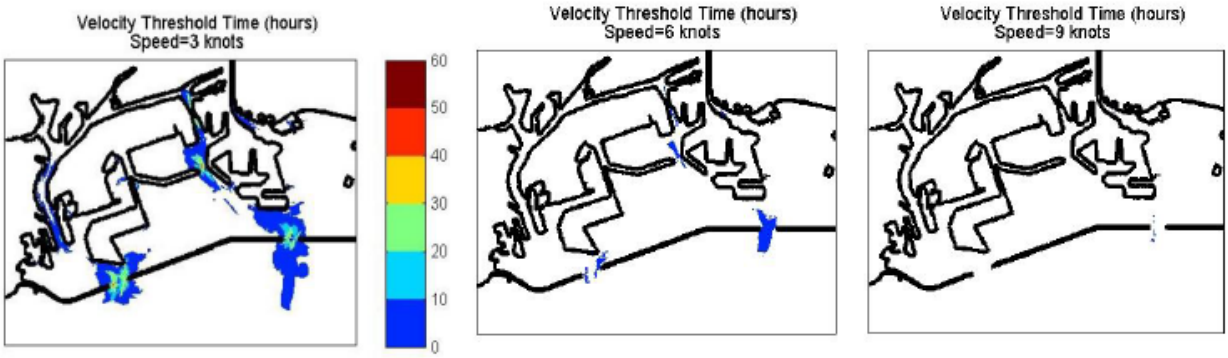
Playbook Plan B
(based on 2010 M8.8 Chile Event)

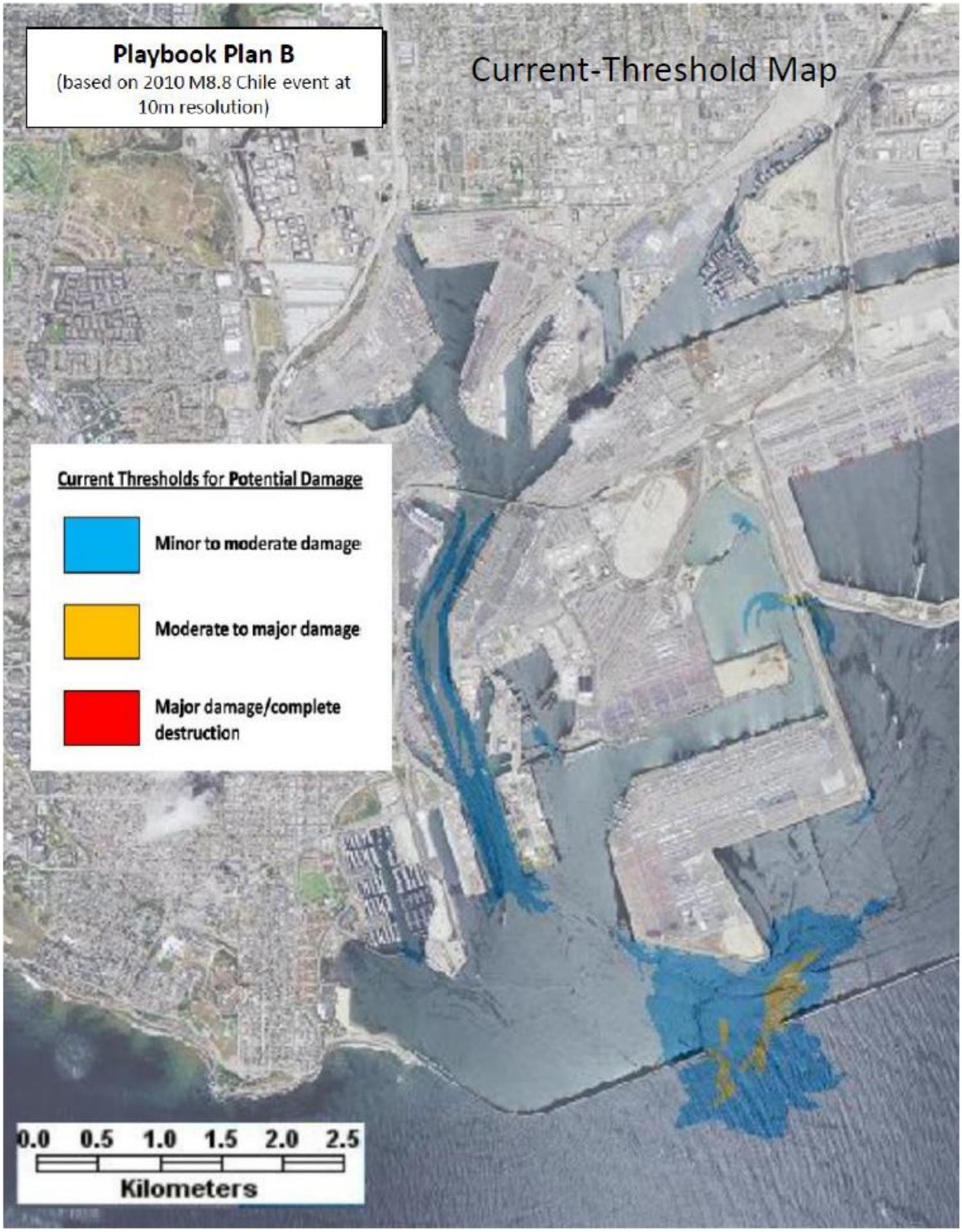
Background Information:
Alert level = Advisory
Peak Amplitude = 0.7 meters (modeled)
Peak Velocity = 7 knots
Projected duration of strong currents (see location map below):
3-6 knots = 30 hrs; 6-9 knots = 10 hrs; >9 knots = 0 hrs

Specific Instructions:

- Follow general guidance for Advisory-level tsunamis (Page 5)
- Strong currents and potential scour are expected in areas identified in blue and gold on the map to the right. Consider relocating vessels located within 100 meters (300 feet) of these areas.
- Specific areas where vessels should be relocated from and docks secured:
    - Vessels can be moved to non-blue areas of the port.
    - …… (completed with maritime community input)

Safe areas for repositioning vessels within POLA:
…..(completed with maritime community input)




Playbook Plan B
(based on 2010 M8.8 Chile event at 10m resolution)
Current-Threshold Map
Current Thresholds for Potential Damage
Minor to moderate damage
Moderate to major damage
Major damage/complete destruction
0.0 0.5 1.0 1.5 2.0 2.5
Kilometers

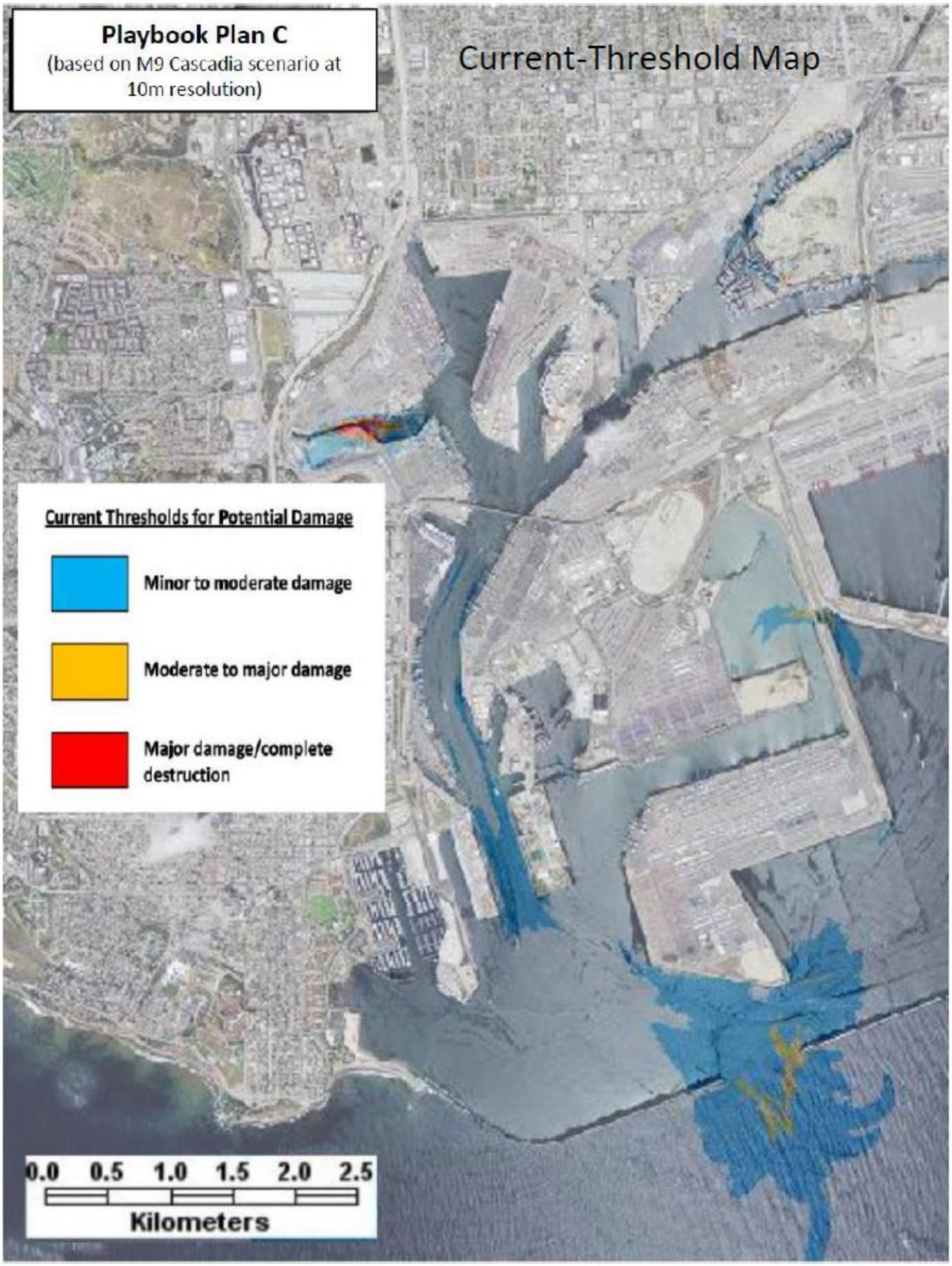
Playbook Plan C
(based on M9 Cascadia Scenario)

Background Information:
Alert level = Advisory or Warning (Warning Center may not have time to distinguish)
Peak Amplitude = 1 meters (modeled)
Peak Velocity = 7 knots
Projected duration of strong currents (see location map below):
3-6 knots = 50 hrs; 6-9 knots = 10 hrs; 9 knots = 0 hrs

Specific Instructions:

- Follow general guidance for Advisory-level tsunamis (Page 5)
- Strong currents and potential scour are expected in areas identified in blue on the map to the right. Consider relocating vessels located within 100 meters (300 feet) of these areas.
- Specific areas where vessels should be relocated and docks secured:
    - Vessels can be moved to non-blue areas of the port.
    - ..... (completed with maritime community input)

Safe areas for repositioning vessels within POLA:
..... (completed with maritime community input)


Playbook Plan C
(based on M9 Cascadia scenario at 10m resolution)
Current-Threshold Map
Current Thresholds for Potential Damage
Minor to moderate damage
Moderate to major damage
Major damage/complete destruction
0.0 0.5 1.0 1.5 2.0 2.5
Kilometers

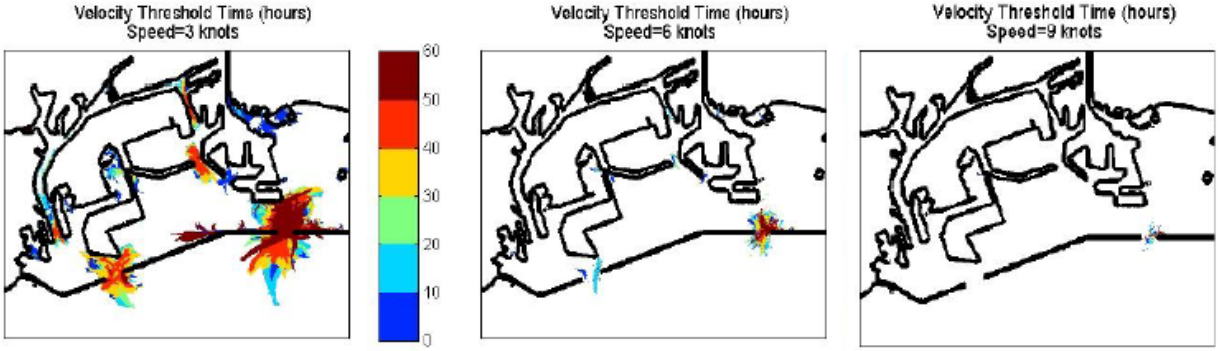
Playbook Plan D
(based on M9.4 North Chile Scenario)

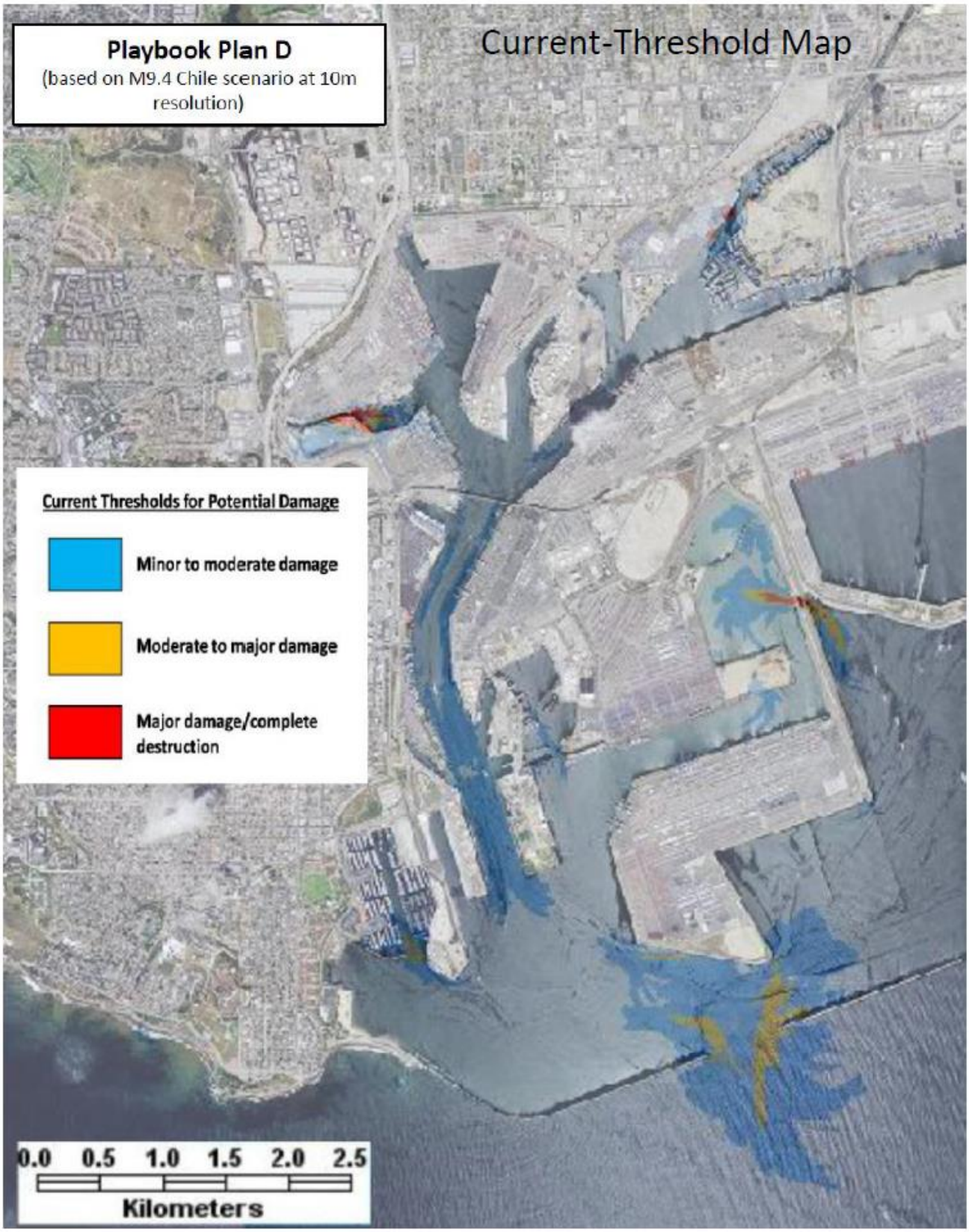
Background Information:
Alert level = Warning
Peak Amplitude = 1.5 meters (modeled)
Peak Velocity = 9+ knots
Projected duration of strong currents (see location map below):
3-6 knots = 50 hrs; 6-9 knots = 10 hrs; >9 knots = 0 hrs

Specific Instructions:

- Follow general guidance for Warning-level tsunamis (Page 5)
- Strong currents and potential scour are expected in areas identified in blue and gold on the map to the right. Consider relocating vessels located within 100 meters (300 feet) of these areas.
- Specific areas where vessels should be relocated from and docks secured:
    - Vessels can be moved to non-blue areas of the port.
    - …… (completed with maritime community input)

Safe areas for repositioning vessels within POLA:
…..(completed with maritime community input)




Playbook Plan D
(based on M9.4 Chile scenario at 10m resolution)
Current-Threshold Map
Current Thresholds for Potential Damage
Minor to moderate damage
Moderate to major damage
Major damage/complete destruction
0.0 0.5 1.0 1.5 2.0 2.5
Kilometers

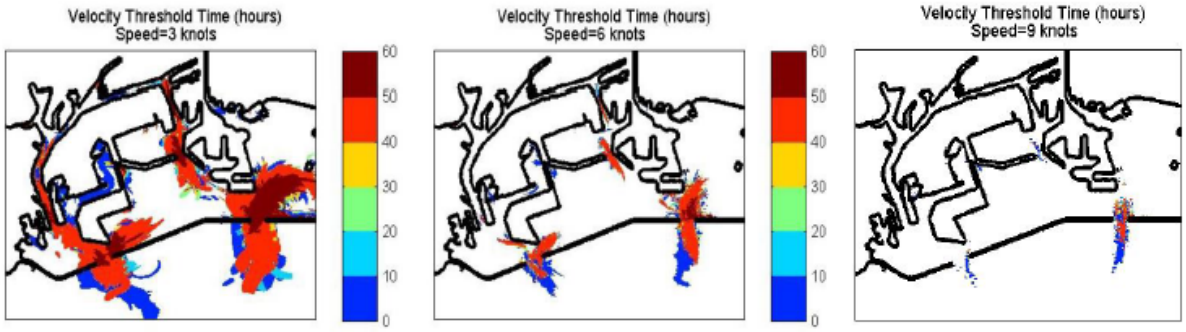
Playbook Plan E
(based on M9.2 Eastern Aleutian-Alaska Scenario)

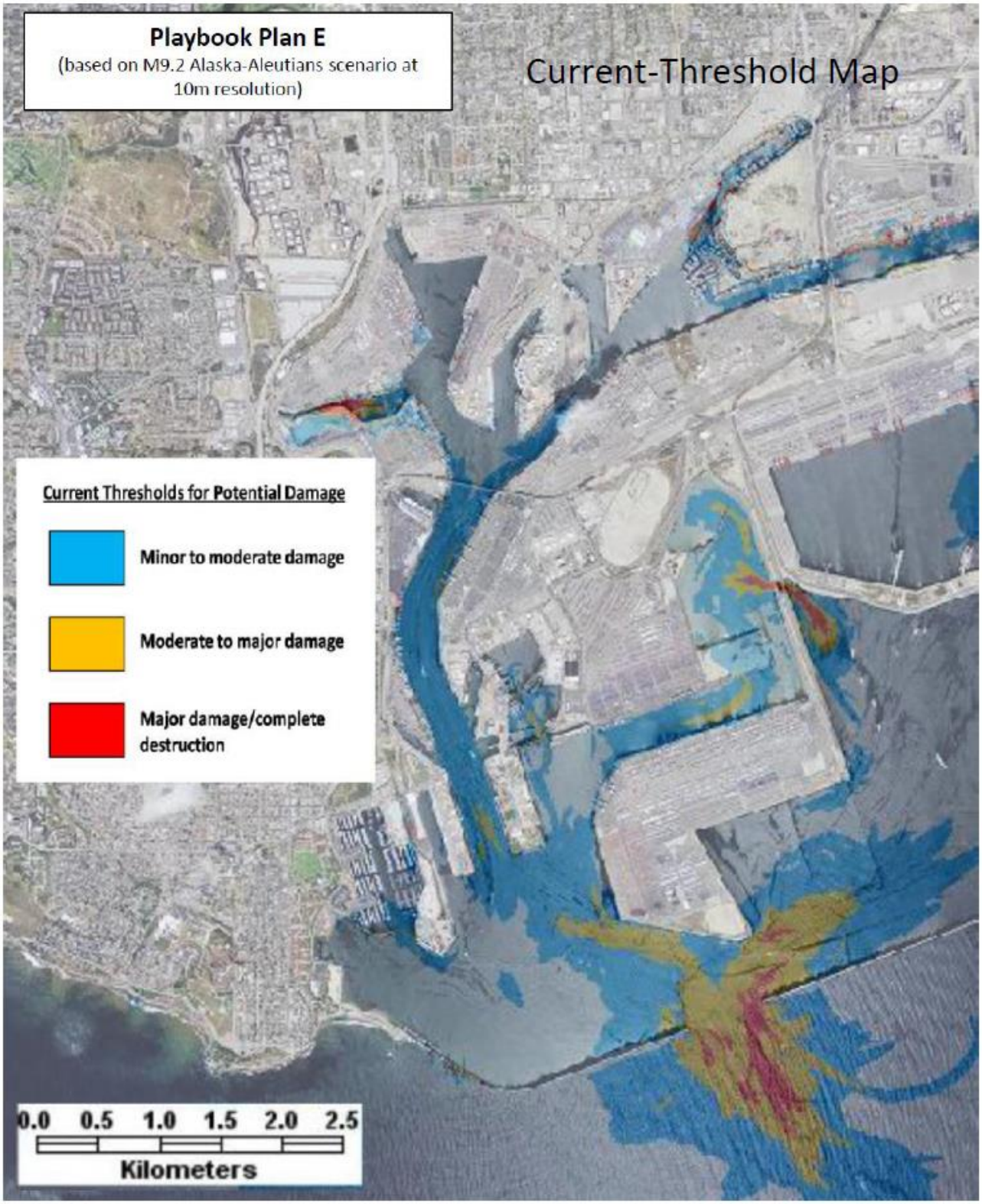
Background Information:
Alert level = Warning
Peak Amplitude = 2+ meters (modeled)
Peak Velocity = 12+ knots
Projected duration of strong currents (see location maps below):
3-6 knots = 60+ hrs; 6-9 knots = 40 hrs; >9 knots = 10 hrs

Specific Instructions:

- Follow general guidance for Warning-level tsunamis (Page 5)
- Strong currents and potential scour are expected in areas identified in blue – yellow-red on the map to the right. Consider relocating vessels located within 100 meters (300 feet) of these areas.
- Specific areas where vessels should be relocated from and docks secured:
    - Vessels can be moved to non-blue areas of the port.
    - (completed with maritime community input)

Safe areas for repositioning vessels within POLA:
(completed with maritime community input)




Playbook Plan E
(based on M9.2 Alaska-Aleutians scenario at 10m resolution)
Current-Threshold Map
Current Thresholds for Potential Damage
Minor to moderate damage
Moderate to major damage
Major damage/complete destruction
0.0 0.5 1.0 1.5 2.0 2.5
Kilometers

Notable Historical Tsunamis: The following table provides very basic information about historical tsunami events; not all tsunamis are represented, especially minor or small tsunamis. Note that the largest, most damaging tsunamis in Los Angeles County history have come from large earthquakes in the Alaska-Aleutian Islands and Chile regions as distant tsunami sources and a potential submarine landslide as a local source. Although the potential for local tsunamis exists, they are much less frequent than distant source tsunamis.

Notable Historical Tsunamis in Los Angeles County

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

OBS = observed tsunami activity
NR = No damage or severe conditions reported

- Distant Source - Tsunamis without felt earthquakes

- Local Source - Earthquake and tsunami together

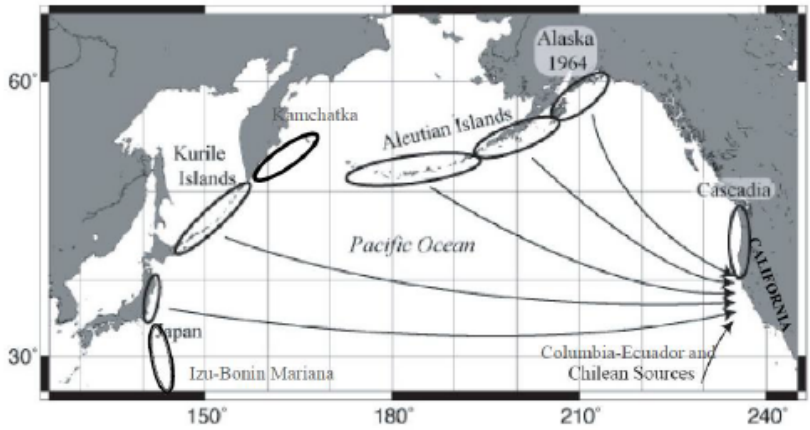
Date	Magnitude-Source area	Tsunami location	Run-Up/Amp	Remarks
7/10/1855	multiple local Eqs	Santa Monica	?	"...considerable commotion in the water, attended by a strong rushing sound..."
8/13/1868	M8.5 - Chile	LA/San Pedro	2 ft	"...the loading dock was submerged..."
5/10/1877	M8.3 - Chile	LA/San Pedro	6 ft	"...The current was frightfully swift to look at..."
8/10/1879	moderate local EQ	Santa Monica	?	Minor "tidal wave" followed EQ
4/13/1923	M7.2 - Kamchatka	LA/San Pedro	?	"...ships had difficulty holding their lines due to swirling tides..."
8/30/1930	meteotsunami?	Santa Monica	10 ft	One person killed due to high surf; conjecture on tsunami source; possible LS from local M5.2 EQ
4/1/1946	M8.8 – Aleutian Islands	LA/San Pedro	3 ft	Broke ships from moorings
		Long Beach	1 ft	NR
		Catalina	6 ft	Damage to docks
11/4/1952	M9.0 - Kamchatka	Santa Monica	2 ft	NR
		LA/San Pedro	1 ft	Docking ferry problematic
		Long Beach	1 ft	NR
3/9/1957	M8.6 - Aleutian Islands	Santa Monica	2 ft	NR
		LA/San Pedro	1 ft	NR
		Long Beach	1 ft	NR
5/22/1960	M9.5 - Chile	Santa Monica	5 ft	NR
		LA/San Pedro	3 ft	One death (swimmer); $1M in damages; 800 small craft unmoored, 200 damaged, 40 sunk
		Long Beach	3 ft	Dock damage
		Alamitos Bay	2 ft	NR
		Catalina	2 ft	NR
3/28/1964	M9.2 – Alaska	Santa Monica	3 ft	One boat sunk; $100k damage at Marina Del Rey
		LA/San Pedro	2 ft	One death to longshoreman by falling object; $250k in damages; 100 boats unmoored, 6 sunk
		Long Beach	?	$100k in damages
		Alamitos Bay	2 ft	NR
		Catalina	2 ft	NR
11/29/1975	M7.1 - Hawaii	Catalina	4 ft	Damage to dock and boats
9/29/2009	M8.0 – Samoa	LA/San Pedro	1 ft	NR
2/27/2010	M8.8 – Chile	Santa Monica	2 ft	Minor damage in Marina Del Rey
		LA/San Pedro	1 ft	Minor damage to docks and boats
		Long Beach	?	NR
		Catalina	3 ft	Minor damage to several docks
3/11/2011	M9.0 - Japan	Santa Monica	3 ft	Minor damage in Marina Del Rey
		Redondo B.	2 ft	One dock, five boats damaged; $15K in damage
		LA/San Pedro	2 ft	Minor damage to boats and docks
		Long Beach	?	Damage to dock and boats
		Catalina	?	Damage to several docks and boats

Modeled Tsunami Scenarios: Because very large tsunamis are infrequent and the likelihood that the largest potential tsunamis have not yet occurred in Los Angeles County, the state tsunami program developed a suite of maximum credible tsunami scenarios as part of their tsunami inundation mapping project for local evacuation planning. The general tsunami wave height for key locations from these scenarios are provided below. As identified in the historical tsunami table, the largest tsunamis could occur from large earthquakes in the Alaska-Aleutian Islands or Chile regions, or from a large submarine landslide offshore.

Tsunami Source Scenario Model Results for Los Angeles County

Near shore tsunami heights (flow depths) for both local and distant source scenarios, in FEET above Mean Sea Level. NOTE: The projections do not include any adjustments for ambient conditions, such as storm surge and tidal fluctuations, and model error (it is very important to note this difference, as those numbers can increase the projected water height during an event).

	TSUNAMI SOURCES	Approximate Travel Time	Leo Corrillo State Beach	Malibu Beach/ Lagoon	Santa Monica Pier	Marina Del Rey	Manhattan Beach	Redondo Beach	Palos Verdes Hills	San Pedro-POLA	Long Beach Middle Harbor-POLB	Long Beach	Naples-Alamitos Bay
Local Sources	M7 Newport-Inglewood Fault	10-15min								2	3	3	3
	M7.5 Channel Isl. Thrust Fault	10-15min	4		3	2	3	3	3				
	M7.2 Anacapa Dume Thrust Fault	10-15min		8	6	3	6	6	5				
	Palos Verdes Landslide 1	10-15min			7	4	6	10	20	4	4	4	5
	Palos Verdes Landslide 2	10-15min								6	5	5	5
	M7.1 Santa Monica Thrust Fault	10-15min		4	5	3	3	4	3				
	M7.7 Catalina Fault	15-20min	4	6	6	5	6	6	6	5	7	7	7
Distant Sources	M9 Cascadia-full rupture	2hr			4	4	4	4	3	3	4	4	4
	M9.2 Alaska 1964 EQ	6hr	5	5	7	6	5	4	4	8	7	9	8
	M8.9 Central Aleutians I	6hr	3		5	5	4	4	4	4	5	5	4
	M8.9 Central Aleutians II	6hr			3	4	3	4	3	3	3	4	4
	M9.2 Central Aleutians III	6hr	6	7	10	10	7	6	5	13	10	11	13
	M9 Kamchatka 1952 EQ	9hr	3										
	M8.8 Kuril Islands II	10hr			3	2	3	2	2	2	3	3	3
	M8.8 Kuril Islands III	10hr			3	3	3	3	2	2	3	3	3
	M8.8 Kuril Islands IV	10hr			3	3	3	3	2	2	3	3	3
	M8.8 Japan II	11hr			3	3	3	3	2	2	3	3	3
	M9.5 Chile 1960 EQ	13hr			5	5	4	4	4	4	7	9	10
	M9.4 Chile North	13hr	5	5	5	6	5	5	5	4	10	9	11
	Maximum Runup - Local Source		**4**	**9**	**8**	**5**	**7**	**11**	**24**	**7**	**8**	**8**	**8**
	Maximum Runup - Distant Source		**7**	**9**	**11**	**11**	**8**	**7**	**5**	**15**	**12**	**13**	**15**

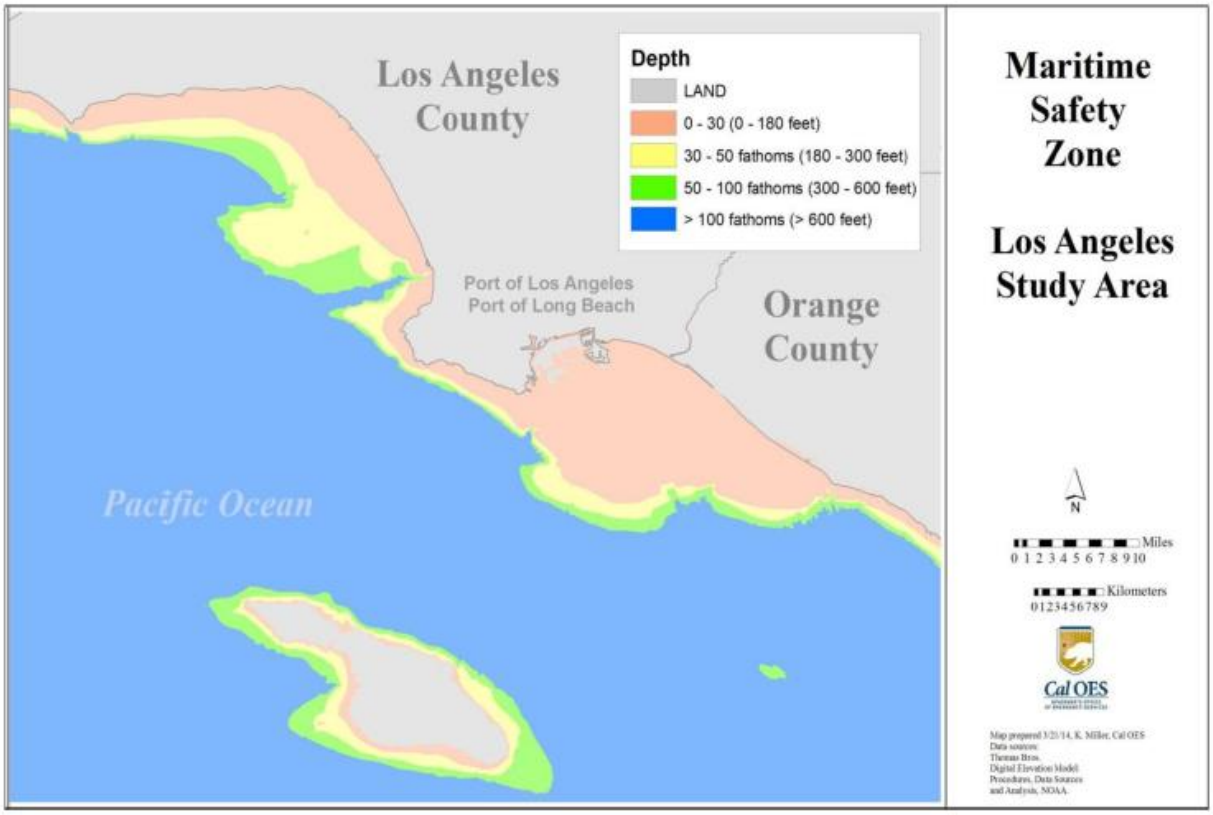


PLAN FOR OFFSHORE EVACUATION OF BOATS

NOTE: The safety of the boating public should outweigh the benefit of saving boats and harbor property during a tsunami.

- For most harbors in California, it is safer to keep boats docked during a tsunami because most tsunamis are relatively small.
- On the rare occasion when a large, damaging tsunami and associated strong currents are expected and there are no safe areas within the harbor, the boat owner may be considering taking their boat offshore.
- There are a number of factors that should be considered prior to recommending boats evacuate offshore prior to the arrival of the tsunamis, including:
  - (1) the SIZE of the tsunami;
  - (2) is there sufficient TIME to get to the 30 fathom depth (180 feet), which has been evaluated as safe depth for boats during distant source tsunamis (map below);
  - (3) the PREPAREDNESS of the boat and its captain to stay at sea over 24 hours;
  - (4) the WEATHER at sea could be as dangerous as the tsunami itself; and,
  - (5) if significant damage occurs within the harbor, boaters should have enough fuel and supplies to travel to a non-damaged harbor.

Note for trailer boat owners: Expect congested boat ramps and remember that you have to get your boat to the trailer, out of the water, and out of the tsunami zone before the tsunami arrives.



STATE TSUNAMI INUNDATION ZONE MAP FOR POLA AND POLB AREA

This tsunami inundation map was prepared to assist cities and counties in identifying their tsunami hazard. It is intended for local jurisdictional, coastal evacuation planning uses. The blue area represents the maximum considered tsunami inundation from a number of extreme, yet realistic, tsunami sources. In other words, people within the blue-colored zones could get wet; people uphill or inland from these areas should be safe during any tsunami. **This map, or the local tsunami evacuation map/plan, should be used for evacuation from a Warning-level tsunami event unless otherwise directed by local emergency management officials.**

For digital copies of this map or inundation maps for other portions of California, visit http://www.tsunami.ca.gov

APPENDIX
Quick Reference Page for Determining Real-Time Maritime Tsunami Response Activities

Step 1: Obtain basic information about the earthquake and tsunami from National Tsunami Warning Center in Alaska, regional National Weather Service office, and/or county emergency manager. **NOTE: Tsunami Alert Level may change in first couple hours after the earthquake; WATCH may be upgraded to ADVISORY or WARNING.**

Earthquake location _____

Earthquake magnitude _____

Tsunami Alert level (circle one) WATCH ADVISORY WARNING

Closest forecasted tsunami amplitude/wave height _____

Forecasted tsunami arrival time _____

Step 2: Tsunami evacuation and response will depend on the amount of time before the tsunami arrival. Four (4) hours is considered the threshold time needed for evacuation. As a quick reference, we offer the following guidance:

1) **If less than four hours before tsunami arrival, we recommend the following:**
   - ADVISORY – evacuate beaches, harbor docks, and piers
   - WARNING – evacuate entire maximum on-land evacuation zone, or follow guidance provided by local emergency manager

2) **If greater than four hours before tsunami arrival**, and your harbor has fully developed its tsunami response Playbook plans, the harbor can utilize the FORECAST AMPLITUDE from Step 1 on the table on the right to identify the appropriate response plan to use.

Reference Pages for Details in Maritime Playbook	Scenario Playbook Plan Letter	Peak Amplitude/ wave height (in meters)
	(No action)	0.2
Page 8-9	A	0.5
Page 10-11	B	0.6
Page 12-13	C	0.8
Page 14-15	D	1.0
Page 16-17	E	1.2