Maritime Guidance for Distant Source Tsunami Events

Coos Bay, Coos County, Oregon

Oregon Maritime Tsunami Response Guidance (MTRG) No. 2020-OR-01

Maritime response guidance in this document is based primarily on anticipated effects of a **maximum-considered distant tsunami event** (scenario *AKMax* of the Oregon Department of Geology and Mineral Industries), although general guidance is also given for a much larger tsunami from an earthquake on the Cascadia subduction zone (see www.oregontsunami.org for more information on these tsunami scenarios). Smaller distant source tsunamis will occur more commonly and are likely to cause much less damage than the *AKMax* scenario. Check with local authorities for more specific guidance that may be appropriate for smaller distant tsunami events.

Oregon Department Geology and Mineral Industries	Oregon Office of Emergency Management	Virginia Institute of Marine Sciences	National Oceanic and Atmospheric Administration	Members of the Oregon Marine Advisory Council

Funded by the National Tsunami Hazard Mitigation Program (NTHMP) and conforms to NTHMP guidance. Document also adapted from the Humboldt Bay Tsunami Maritime Actions website (http://humboldtharborsafety.org/sites/humboldtharborsafety.org/files/BMP%20Tsunami%20Maritime%20Actions%20Small%20Craft%20Final.pdf).

INTRODUCTION

Tsunamis can be triggered by earthquakes anywhere around the Pacific Rim and will cause sudden water level and current changes for many hours after their first arrival. The location of the earthquake plays an important role in determining the tsunami propagation travel time to the coastal community.

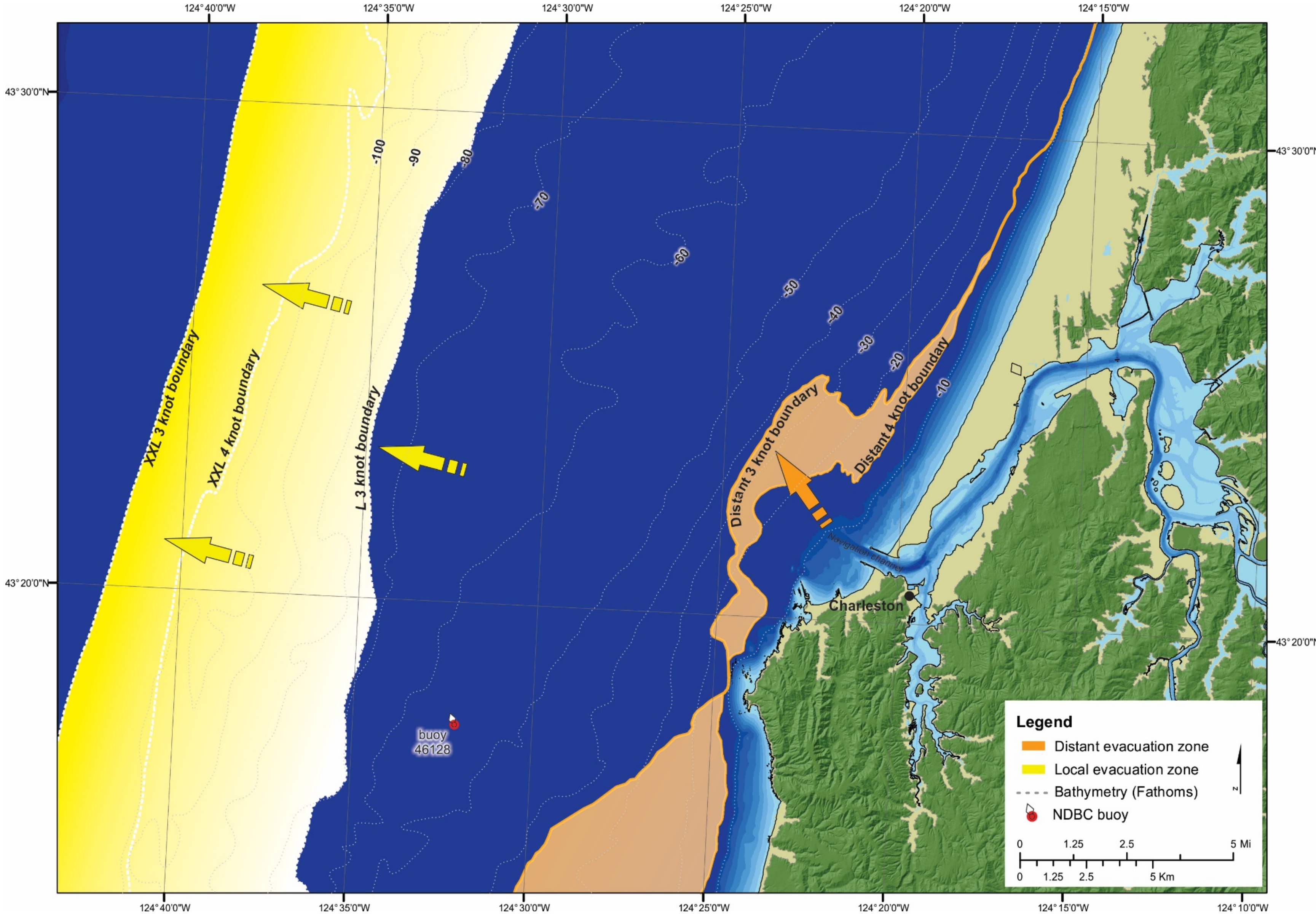
DISTANT TSUNAMIS are caused by great earthquakes far away from the Oregon coast and will arrive at the mouth of Coos Bay (MCB) *approximately* 4 hours or more after the earthquake. Tsunami waves will cause water level and current changes for many hours after first wave arrival.

A locally generated earthquake on the Cascadia subduction zone (CSZ) offshore the Oregon coast will produce catastrophic tsunami waves that will reach the MCB in *approximately* 9 minutes (peak wave arrives in 19 minutes) after the start of the earthquake and will flood the Coos estuary in 20 to 60 minutes. Modeled initial (peak) wave arrival times for a **LOCAL TSUNAMI** are 15 (23) minutes at Charleston, 13 (21) minutes at Barview, 21 (25) minutes at Empire, 24 (29) minutes at Pony Point, and 39 (41) minutes at downtown Coos Bay.

This document provides response guidance in the event of a **DISTANT TSUNAMI**, for maritime vessels, including large ships and small craft such as recreational and commercial fishing vessels. Review DOGAMI Open-File-Report O-20-08 (Allan and others, 2020) for detailed maritime tsunami guidance on distant and local tsunamis affecting the entire Coos estuary. A brief summary of the key actionable responses is provided below for both types of events.

<u>DISTANT Tsunamis</u>: *You have a minimum of 4 hours after the distant earthquake to take action*. If you are on the water, first check with the U.S. Coast Guard before taking any action. If advised to evacuate to deep water and this option is practical for your vessel and your capabilities to remain offshore for an extended period, **proceed to a staging area greater than 25 fathoms (150 ft)** *(orange staging area in Figure 1, located ~2.5 nautical miles northwest of the mouth of Coos Bay [2.4 nautical miles north of the Cape Arago lighthouse])*. **Dangerous currents (> 5 knots) are expected to occur at depths shallower than 15 fathoms, and especially within the MCB**. If conditions do not permit offshore evacuation, dock your boat and get out of the tsunami evacuation zone.
<u>LOCAL Tsunamis</u>: *You have as little as <u>~12 minutes</u> to take action; <u>plan in advance</u>*. If your boat is docked, you do NOT have time to take your vessel offshore; instead, evacuate by foot to high ground immediately. If you are on the water seaward of the MCB at the time of a local earthquake, **proceed to a staging area greater than 80 fathoms (480 ft)** water depth (*pale shaded region in Figure 1, located ~10 nautical miles west of the mouth of Coos Bay. Safety improves significantly with additional westward travel. The preferred staging area is in depths greater than 100 fathoms (600 ft) located 13.4 nautical miles west of the mouth of Coos Bay*). Sail directly toward the nearest deep water or in a general westward direction. **Dangerous currents (> 5 knots) are expected to occur at depths shallower than 80 fathoms (480 ft)**. Note that significant wave heights may be greatly amplified by strong opposing tsunami currents.

Figure 1. Offshore maritime staging area for the Coos Bay area. Map identifies the minimum distance to the DISTANT (orange) and LOCAL (yellow) maritime tsunami evacuations zones offshore the coast. These zones define the region where tsunami currents fall below 4 knots. Maritime safety from tsunami generated currents improves with further westward travel. Note: bathymetric contours on the map are fathoms (1 fathom = 6 ft).



Tsunami Hazards

Tsunami wave impacts are greatest in and around ocean beaches, low-lying coastal areas, and bounded water bodies such as harbors and estuaries. These areas should always be avoided during tsunami events. Any tsunami event can threaten harbors, facilities, and vessels.

Tsunami hazards that can directly affect boats/boaters include:

- Sudden water-level fluctuations, which could result in
  - Docks overtopping piles as water levels rise; and
  - Grounding of boats and docks as water levels drop.
- 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 deep draught ships causing damaging forces to vessels tied to docks.
- Collision with other vessels, 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.

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 (from Lynett and others, 2013) to the right has been used to determine the following relationship (see color codes here for green, yellow, orange, and red areas and on the maps showing tsunami current thresholds (**Figure 2** and Appendix A tsunami current 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

BACKGROUND ON TSUNAMIS

Very large underwater earthquakes are the most likely cause of tsunami waves, which can cause significant damage at very distant shores. Earthquake-caused tsunami waves occur when the seafloor abruptly deforms and vertically displaces (lifts) the overlying water column. The displaced water travels outward in a series of waves that grow in intensity as they encounter shallower water along coastlines. Tsunami wave impacts are greatest in and around ocean beaches, low-lying coastal areas, and bounded water bodies such as harbors and estuaries. ***Potential tsunami wave impact areas should always be avoided during tsunami events.***

Any tsunami event can threaten harbors, facilities, and vessels. Unlike a ***LOCAL*** tsunami, which requires the public to evacuate immediately to high ground (or to deep water if out on the ocean), a ***DISTANT*** tsunami does allow at least some time for local agencies and citizens to take steps to help reduce the expected impacts of tsunami surges. However, the time available for response is minimal—all needed mitigation actions probably cannot be accomplished. Therefore, the actions to be taken must be prioritized and based on life-safety preservation.

The source location of a distant tsunami greatly impacts the ability of local governments to respond and the public to mitigate expected impacts. A tsunami originating in *Chile (14–15 hours away)* or *Japan (9–10 hours away)* will allow much more local mitigation activity than will a tsunami originating in the *Gulf of Alaska or the Aleutian Islands (3.5–5 hours away)*. Of these, the eastern Aleutian Islands represent the closest distant earthquake source to the Oregon coast (~4 hours for the waves to arrive at the MCB).

Response entities and the public should allow enough time to complete the necessary steps to prepare for a ***DISTANT*** tsunami. For example, if you are on the water, first check with the U.S. Coast Guard before taking any action. If advised to evacuate to deep water and this option is practical for your vessel and you are capable of remaining offshore for an extended time period, proceed to a staging area **greater than 25 fathoms (150 ft)** (*orange line in* **Figure 1***, located ~2.5 nautical miles northwest of the mouth of Coos Bay [2.4 nautical miles north of the Cape Arago lighthouse]*). If conditions do not permit maritime evacuation, dock your boat and evacuate out of the ORANGE zone located on the **Coos Bay tsunami evacuation** map; links to various community tsunami evacuation maps are provided on page **16** of this guidance document. Be aware that local mitigation activities will be extensive and could involve large numbers of people, resulting in congestion and delayed actions—it may not be possible to complete normally simple mitigation actions in the time frame available.

NOTABLE HISTORICAL TSUNAMIS IN COOS ESTUARY

Table 1 provides basic information about historical tsunami events either observed (e.g., near Empire) or measured at the Charleston tide gauge on the south-central Oregon coast; some additional minor tsunamis are not included. Here we distinguish between two types of observations:

1. Water heights as observed by an eyewitness (i.e., the maximum elevation of the wave), and
2. Measurements from a tide gauge. In this example, the measured tsunami water is expressed as *wave amplitude*, which is half the height of the tsunami wave.

The largest, most damaging distant-source tsunamis to affect the Coos estuary have come from large earthquakes in the Alaska-Aleutian Islands region (1964) and most recently from Japan (2011) (**Table 1**). The peak wave amplitude and damage information provided in **Table 1** may help guide port authorities with their decision making when responding to future Advisory and Warning level tsunamis in the area. For example, the 1964 Alaska tsunami provides a threshold, since damage was reported for one site in Coos Bay (near Empire) for a tsunami wave amplitude (wave height) of 1.7 m (5.6 ft), occurring on a higher tide.

Table 1. Historical tsunami events observed (e.g., Empire) or measured (Charleston) on the south-central Oregon coast since 1964 (NGDC, 2017). Bold rows highlight the effects of the 1964 event that resulted in some damage, versus other events that produced small to negligible tsunami waves.

Location	Event	Peak Amplitude Observed		NTWC Tsunami Alert Level Assigned	Tides During First 5 Hours	Damage Summary
		(m)	(ft)			
Empire	**1964 M9.2 Alaska**	**1.7**	**5.6**	**Warning**	**High***	**damage reported**
Charleston	2006 M8.3 Kuril	0.19	0.6	—	Low	no damage reported
Charleston	2009 M8.0 Samoa	0.13	0.4	Advisory**	High	no damage reported
Charleston	2010 M8.8 Chile	0.16	0.5	Advisory**	Low	no damage reported
Charleston	2011 M9.0 Japan	0.71	2.3	Warning**	Low	no damage reported
Charleston	2012 M7.7 Canada	0.13	0.4	Information	High	no damage reported

*Alaska 1964 arrival on PNW coast was at mean high water flood tide.

**Alert assigned by forecast OUTSIDE of bay.

Lessons Learned in Northern California from the March 11, 2011 Japanese Tsunami

During the March 11, 2011 event, nearly two-thirds of the Crescent City fishing boats headed to sea (Wilson and others, 2013). Many were prepared and practiced evacuation from the harbor prior to this event. Once the tsunami hit and operators realized they were unable to return to Crescent City harbor, decisions had to be made as to where to go because of a huge storm approaching the coast. Some vessels had enough fuel to make it to Brookings Harbor in Oregon or to Humboldt Bay, California. Some smaller vessels did not have enough fuel and made the choice to re-enter Crescent City harbor to anchor. Some Crescent City captains had never been to Humboldt Bay and some were running single handed as they did not have enough time to round up crewmen. As with captains who chose to go to Brookings, captains heading to Humboldt Bay kept in close contact with each other for safety and for moral support. Even though the tsunami initially impacted the west coast on the morning of March 11, 2011, the largest surges in Crescent City did not arrive until later in the evening. In summary, the lessons learned reflect:

1. It is recommended that harbors and vessels practice their offshore evacuation plan;
2. If evacuating to deep water, ensure that your vessel is equipped to handle the ocean conditions and has sufficient fuel and supplies to remain offshore for several days;
3. Recognize that the port you left may have been damaged by the tsunami, such that you may not be able to return to the same port; and
4. The largest surges may not arrive until much later.

ACTIONABLE TSUNAMI ALERT LEVELS

Tsunami Advisories and Warnings are the two actionable alert levels for maritime communities. For both Advisory and Warning level events, it is important that clear and consistent directions are provided to the entire boating community and to waterfront businesses. Sign up to receive notifications from the National Tsunami Warning Center in Palmer, Alaska (https://ntwc.ncep.noaa.gov/?page=productRetrieval), which issues two types of bulletins that require action by Oregon boaters:

⚠ Tsunami Advisories	⚠ Tsunami Warnings
Peak tsunami wave heights of 1 to 3 feet are expected, indicating strong and dangerous currents can be produced in harbors near the open coast. • **SIGNIFICANT** tsunami currents or damage are possible **in the Coos estuary** near harbor entrances or narrow constrictions.	Tsunami wave heights could exceed 3 feet in harbors near the open coast, indicating very strong, dangerous currents and inundation of dry land is anticipated. • **SIGNIFICANT** tsunami currents or damage are possible **in the Coos estuary**. • Depending on the size of the tsunami and the tidal conditions, **docks may overtop the pilings.**

GENERAL GUIDANCE ON RESPONSE TO NOAA ADVISORIES AND WARNINGS

In and near Coos estuary

Tsunami Advisories

- **<u>During the *DISTANT* event</u>** (before the tsunami arrives):
  - ➢ Evacuate from all structures and vessels in the water.
  - ➢ Access of public along waterfront areas will be limited by local authorities.
  - ➢ All personnel working on or near the water should wear personal flotation devices.
  - ➢ Port authorities will 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.
  - ➢ If you are on the water,
    - Check with the U.S. Coast Guard (USCG) before taking any action.
    - Monitor VHF FM Channel 16 and the marine WX channels for periodic updates of tsunami and general weather conditions; additional information will be available from NOAA Weather Radio.
    - If advised that offshore evacuation is an option and this is practical for your vessel and you are capable of staying offshore for an extended time period, **<u>proceed to depths greater than 25 fathoms (150 ft)</u>**.
    - ➢ **<u>For the Coos estuary, head to the orange staging area in Figure 1, located ~2.5 nautical miles northwest of the mouth of Coos Bay (2.4 nautical miles north of the Cape Arago lighthouse)</u>**.

- **<u>After the event</u>**: Port authorities will not allow public to re-enter structures and vessels in the water until the Advisory is cancelled.

Tsunami Warnings

- **<u>During the *DISTANT* event:</u>**
  - ➢ Access of public along waterfront areas will be limited by local authorities.
  - ➢ Port authorities will shut off fuel to fuel docks, and all electrical and water services to all docks.
  - ➢ If you are on the water,
    - Check with the U.S. Coast Guard (USCG) before taking any action.
    - Monitor VHF FM Channel 16 and the marine WX channels for periodic updates of tsunami and general weather conditions; additional information will be available from NOAA Weather Radio.

  If advised that offshore evacuation is an option and this option looks practical for your vessel and you are capable of staying offshore for an extended time period, **<u>proceed to depths greater than 25 fathoms (150 ft).</u>**

  (continued on next page)

- **For the Coos estuary, head to the orange staging area in Figure 1, located ~2.5 nautical miles northwest of the mouth of Coos Bay (2.4 nautical miles north of the Cape Arago lighthouse).**

If conditions do not permit marine evacuation, dock your boat and get out of the ***DISTANT Tsunami Evacuation Zone*** (ORANGE zone on the **Coos Bay tsunami evacuation** map; links to various community tsunami evacuation maps are provided on page **16** of this guidance document).

- VESSELS considering leaving the harbor and heading to sea, please consider the following:
  - Make sure your family is safe first.
  - Check tide, bar, and ocean conditions.
  - Check the weather forecast for the next couple of days.
  - Ensure you have enough fuel, food, and water to last a couple of days.
  - Have someone drive you to the marina so your vehicle is not in the DISTANT Tsunami Evacuation Zone (ORANGE zone on the **Coos Bay tsunami evacuation** map; links to various community tsunami evacuation maps are provided on page **16** of this guidance document).
  - PLEASE REMEMBER: There may be road congestion. There may also be vessel congestion in the harbor as ships, barges, and other vessels attempt to depart at the same time. All vessels should monitor VHF Channel 16 and use extreme caution. NEVER impede another vessel.
  - If you do not have time to accomplish your goal, you should not make the attempt.
- **VESSELS that stay in port** should check with local port authorities for guidance on what is practical or necessary with respect to vessel removal or mooring options, given the latest information on the distant tsunami event; then go outside the DISTANT Tsunami Evacuation Zone (ORANGE zone on the **Coos Bay tsunami evacuation** map; links to various community tsunami evacuation maps are provided on page **16** of this guidance document).

- **After the event:**
  - The "CAUTIONARY RE-ENTRY" DOES NOT MEAN THAT THE HARBOR IS OPEN. The “CAUTIONARY RE-ENTRY” message is for land entry only.
  - Mariners at sea should stay at sea until after the United States Coast Guard has issued a message stating that the port is open for traffic.
  - Check with your docking facility to determine its ability to receive vessels. Adverse tsunami surge impacts may preclude safe use of the harbor. Vessels may be forced to anchor offshore or to travel great distances to seek safe harbor. An extended stay at sea is a possibility if the harbor is impacted by debris or shoaling. Make sure your vessel is prepared to stay at sea. Where possible, mariners should congregate for mutual support while at sea, at anchor, or during transit elsewhere.

If in an onshore assembly or evacuation area, check with local authorities for guidance before returning to the inundation zone.

Figure 2 presents a map of the (*top*) maximum water levels and (*bottom*) tsunami current velocities and expected port damage resulting from a maximum-considered ***DISTANT*** tsunami initiating near the eastern Aleutian Islands (Allan and others, 2020). More detailed maps specific to Charleston and the Coos Bay (upper estuary) are included at the end of this report on page **16**.

The highest tsunami water levels are observed along the open coast, especially offshore the North Spit. Dangerous conditions are also observed at the MCB, Charleston, Barview, by the Coos airport, and near Jordon Point.

Modeled tsunami currents indicate potentially dangerous currents across much of the estuary. Strong currents exceeding 9 knots (hot colors) are expected to occur at the MCB, in the navigation channel near the mouth and adjacent to Charleston and Barview, by the Coos Bay airport, and in the narrows between Jordon Point and Pony Point (**Figure 2**, *bottom*). Of major concern will be the interaction of incoming tsunami waves with opposing currents generated during an ebb tide coupled with seaward directed tsunami drainage, which will likely contribute to the amplification of waves occurring near the mouth (see Appendix A).

Within the estuary, the model results indicate that large parts of the estuary would be affected by currents in the 3–6 knot range (**Figure 2**, *bottom*). Currents of this magnitude are likely to cause moderate damage to facilities located adjacent to the Charleston harbor. For vessels moored in the harbor, currents of this magnitude could result in significant damage to the boats, including boats breaking their mooring lines and smashing into other vessels. For large ships moored at Coos Bay in the upper estuary and elsewhere, ship operators may need to add additional mooring lines and/or drag anchors to help stabilize larger vessels.

Evacuation upriver toward Coos Bay (upper estuary) or offshore to the *DISTANT* staging area may be feasible for some smaller boats and vessels.
Maritime evacuation will depend on how long it takes for a vessel to get underway (a conservative estimate is about 1 hour for large ships), the availability of river pilots (who may be already committed or unavailable in the timeframe required), the speed at which a vessel can travel, and offshore marine conditions. For example, the distance from Charleston to Coos Bay (where tsunami currents fall below 4 knots) is 11 nautical miles (**Table 2**). For a vessel traveling at 6 knots, this equals ~1 hour 50 minutes travel time. Offshore evacuation is not recommended for vessels moored at Coos Bay in the upper estuary. This is because the distance to the distant tsunami staging area (ORANGE zone) and 15-fathom line offshore the MCB is 14 nautical miles, and a vessel traveling at 6 knots would take ~2 hours 20 minutes to reach areas of expected low currents, providing little buffer between leaving the estuary and the arrival of the tsunami. The latter also assumes that conditions at the MCB are manageable for vessels trying to move out through the mouth into the Pacific Ocean.

Figure 2. (top) Maximum water levels and (bottom) tsunami current velocities and expected port damage resulting from the AKMax DISTANT tsunami impacting the Coos estuary. Dangerous eddies and whirlpools can be expected in narrow channel constrictions such as adjacent to the jetties, the port breakwater, and next to the port dock facilities. Time histories of water levels and currents are provided in Appendix A for stations 7 (MCB), 10 (Empire), 15 (Jordon Point), and 31 (Coos Bay, upper estuary).

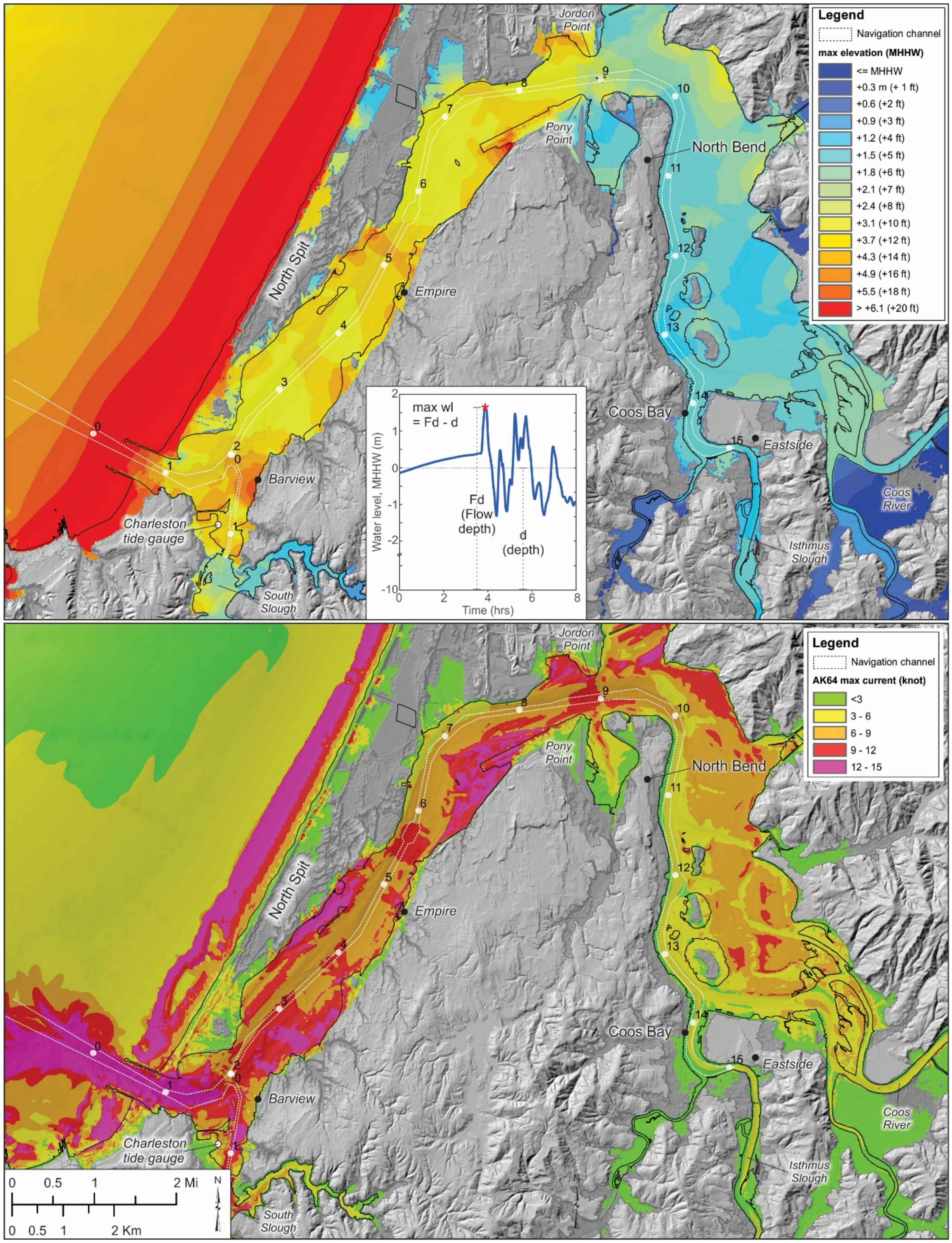


Table 2. Maritime evacuation times to nearest offshore (where currents fall below 4 knots) and upriver staging destinations. Evacuations times assume an average vessel speed of 6 knots. (NM = Nautical Miles)

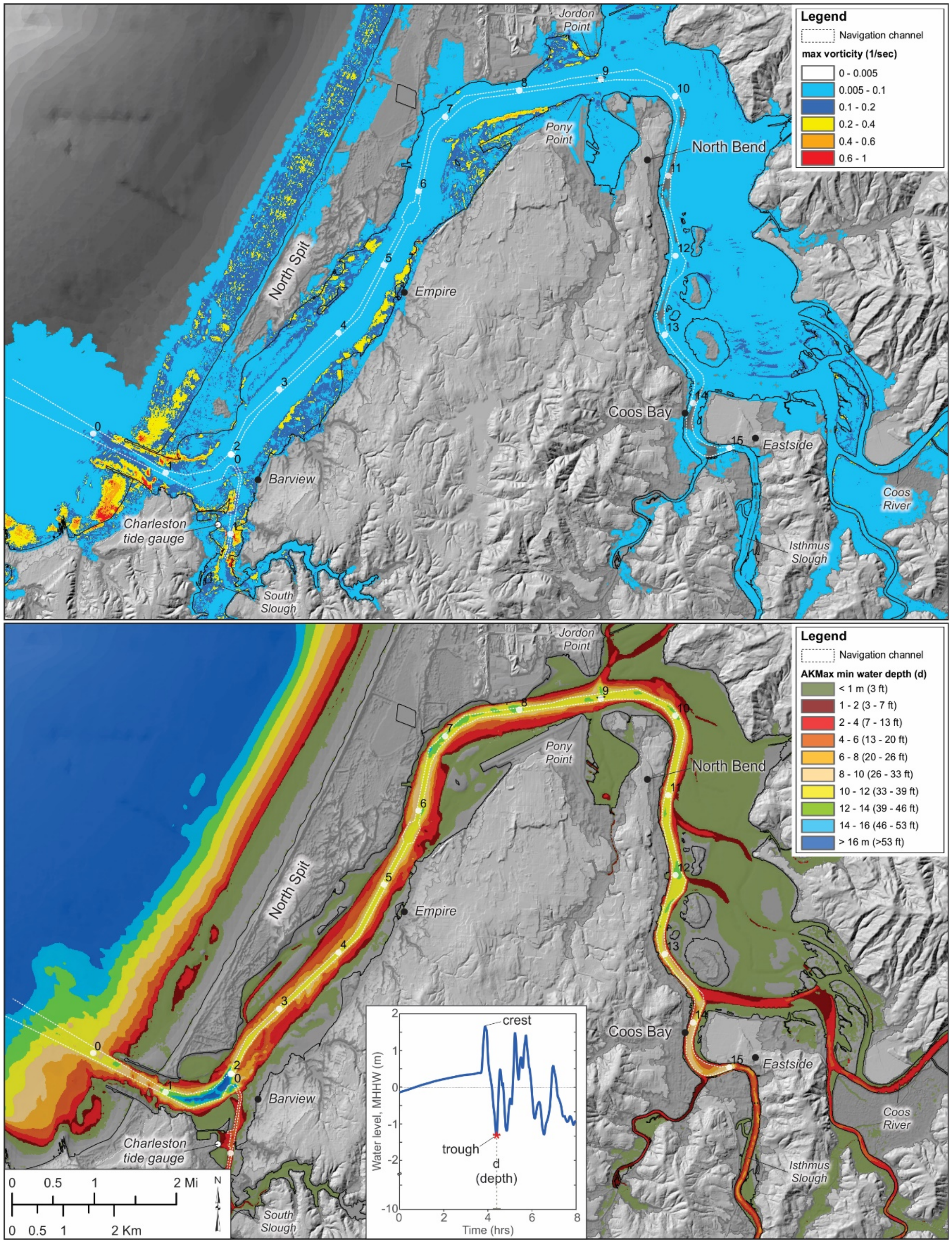
Location	Distance to Offshore Staging (NM)	Time to Safety	Distance to Upriver Staging (NM)	Time to Safety
Charleston	4.1	40 min	11.0	1 hours 50 min
Lower Jarvis Range	7.1	1 hour 11 min	6.8	1 hours 8 min
Jordon Pt	9.3	1 hour 33 min	4.5	45 min
Coos Bay (upper estuary)	14	2 hours 20 min	NA	NA

Strong current velocities are expected within the ports, at the entrance to the Charleston marina, and around the docks.
Besides powerful currents, the navigation channel, ports, marinas and docks may also be susceptible to the occurrence of whirlpools and gyres (**Figure 3**, *top*). Strong currents and vorticity will be especially significant at the Charleston marina (see Charleston maps in appendix). Rise of water above prevailing tide is expected to be +12 ft above the tide within the Charleston marina (**Figure 2**, *top*), +10 ft at Lower Jarvis Range, +12 ft near Jordon Point, decreasing to +5 ft at Coos Bay in the upper estuary. Floating dock pilings should therefore be constructed to handle this change in water level plus an appropriate tide such as Mean Higher High Water (MHHW). MHHW is 7.6 ft above geodetic mean sea level (NAVD88) in this area.

Dangerous tsunami currents are expected to persist for at least 4 hours after the initial wave arrival.
Tsunamis may be characterized by multiple surges of water lasting at least several hours. Withdrawing tsunami waves (**Figure 3**, *bottom*, red/brown colors; olive color indicates complete exposure of the bed) will rapidly drain the estuary and can ground vessels, making them vulnerable to being sunk by the next tsunami surge. This is likely to be an issue over large parts of the estuary, while grounding in the navigation channel is unlikely to occur.

Wind waves can be significantly amplified due to the occurrence of opposing currents.
Besides the occurrence of strong currents at the mouth of Coos Bay, strong currents may be felt out on the ocean. Model simulations for the Coos Bay area indicate that strong currents will be especially significant up to 2.25 nautical miles west of the MCB (**Figure 2**, *bottom*), with strong currents persisting for several hours after the first wave arrives. Wind waves may also be amplified, especially on the tsunami outgoing (ebb) flow (Appendix A). For example, a 5-ft wave could be amplified 12–30% by a 3-knot opposing current generated by a tsunami, and by as much as 95% as currents approach 6 knots. If using existing single-point moorings or when anchoring, be aware that the dead-man or anchor could move or the mooring lines or chains could break because of strong or changing currents. Initial evaluations and some field observations of anchor stability indicate that currents greater than 3-4 knots will move a dead-man or anchor.

Figure 3. Maximum vorticity (top) and minimum water depths (bottom) generated by a the AKMax DISTANT tsunami impacting the Coos estuary. Top plot is a measure of the potential for rotation (gyres and whirlpools – hot colors indicate strong potential), while the bottom shows the expected minimum water depths from tsunamis.



ADDITIONAL GUIDANCE

Do Your Homework

Check the DOGAMI Tsunami Clearinghouse (http://www.oregontsunami.org) for detailed information on tsunami hazards in your area and tips on preparedness. Preparedness information is also available from Oregon Emergency Management (https://www.oregon.gov/OEM/hazardsprep/Pages/Tsunami.aspx). Download and review the statewide tsunami maritime guidance brochure (https://www.oregongeology.org/pubs/tsubrochures/TsunamiBrochureMaritime.pdf). For general information on tsunami maritime hazards consult https://www.tsunami.noaa.gov/ and the information below.

Know real-time and permanent mitigation measures appropriate for your area

This information can be used 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 local hazard mitigation plans. Although these products, plans, and related mitigation efforts will not eliminate all casualties and damages from future tsunamis, they will provide a basis for reducing future impacts on life-safety, infrastructure, and recovery in Oregon maritime communities.

Real-Time Response Mitigation Measures	Permanent Mitigation measures
Move boats and ships out of harbors	Fortify and armor breakwaters
Reposition ships within harbor	Increase size and stability of dock piles
Move large, deep draft ships from harbor entrances	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	Reduce exposure of petroleum/chemical facilities
Move hazardous materials away from water	Strengthen boat/ship moorings
Move buoyant assets away from water	Construct floodgates
Stage emergency equipment outside affected area	Prevent uplift of wharfs by stabilizing platform
Activate Mutual Aid System as necessary	Add debris deflection booms to protect docks
Activate Incident Command at evacuation sites	Make harbor control structures tsunami resistant
Alert key first responders at local level	Construct breakwaters farther away from harbor
Aid traffic evacuating harbor	Install tsunami warning signs
Personnel to assist rescue, survey and salvage	Strengthen equipment/assets (patrol/tug/fireboats, cranes, etc.) to assist response activities
Identify boat owners/live-aboards; establish phone tree, or other notification process	

Consult your community tsunami evacuation map

Use the tsunami evacuation maps to determine where it is safe from a ***DISTANT*** (orange zone) or ***LOCAL*** (yellow zone) tsunami:

Coos Bay tsunami evacuation maps

Detailed tsunami evacuation zones can be found online at:

- PDFs = https://www.oregongeology.org/tsuclearinghouse/pubs-evacbro.htm
- Interactive web portal map: http://nvs.nanoos.org/TsunamiEvac

Regional maps covering Coos Bay, North Bend, Empire, Barview and Charleston may be found here:

https://www.oregongeology.org/pubs/tsubrochures/CoosBayEvac.pdf

Smartphone app:

iPhone: https://itunes.apple.com/us/app/tsunamievac-nw/id478984841?mt=8

Warning: After an earthquake and tsunami, cell phone towers might be damaged.
Know and practice your evacuation plan beforehand.

Additional Resources:

Oregon Tsunami Clearinghouse: http://www.oregontsunami.org

Oregon Emergency Management: https://www.oregon.gov/OEM/

Oregon Statewide Maritime Evacuation Guidance brochure:

https://www.oregongeology.org/pubs/tsubrochures/TsunamiBrochureMaritime.pdf

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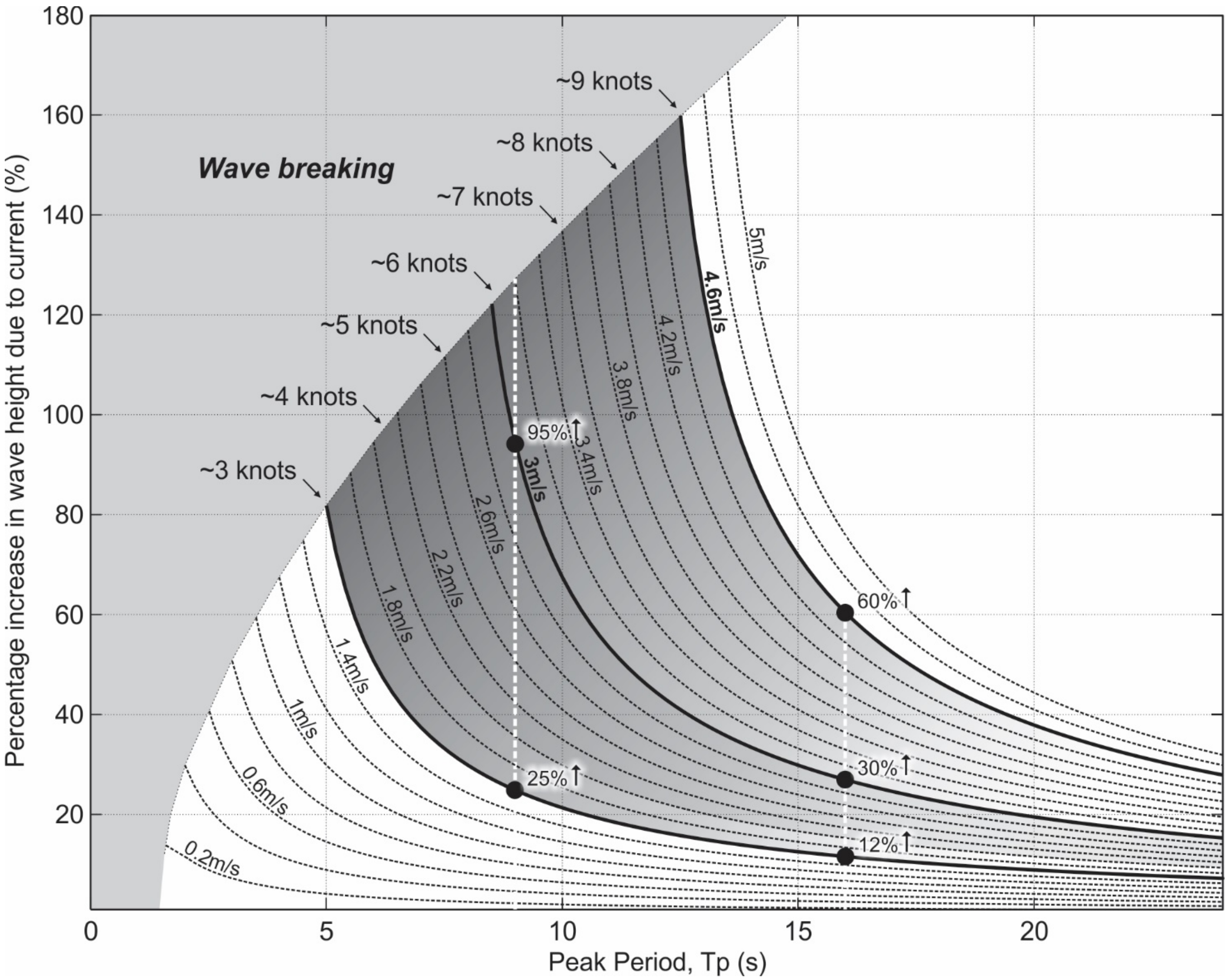
APPENDIX A — ADDITIONAL MAPS

Unless otherwise indicated, maps on the following pages are from Allan and others (2020):

- Plot showing change in wave amplitudes based on opposing currents
- Tsunami wave arrival times for an eastern Aleutian Islands (***DISTANT***) earthquake and tsunami
- Maximum water levels and currents at the Charleston marina
- Vorticity and minimum water depths at the Charleston marina
- Maximum water levels and currents at Coos Bay, upper estuary
- Vorticity and minimum water depths at Coos Bay, upper estuary
- Time histories of water levels for the MCB, Empire, Jordon Point, and Coos Bay (upper estuary) sites for an AKMax ***DISTANT*** tsunami
- Time histories of tsunami currents for the MCB, Empire, Jordon Point, and Coos Bay (upper estuary) sites for an AKMax ***DISTANT*** tsunami

Wave amplification estimate. Plot shows change in wave amplitudes based on opposing currents (from Allan others, 2018):



How to use:

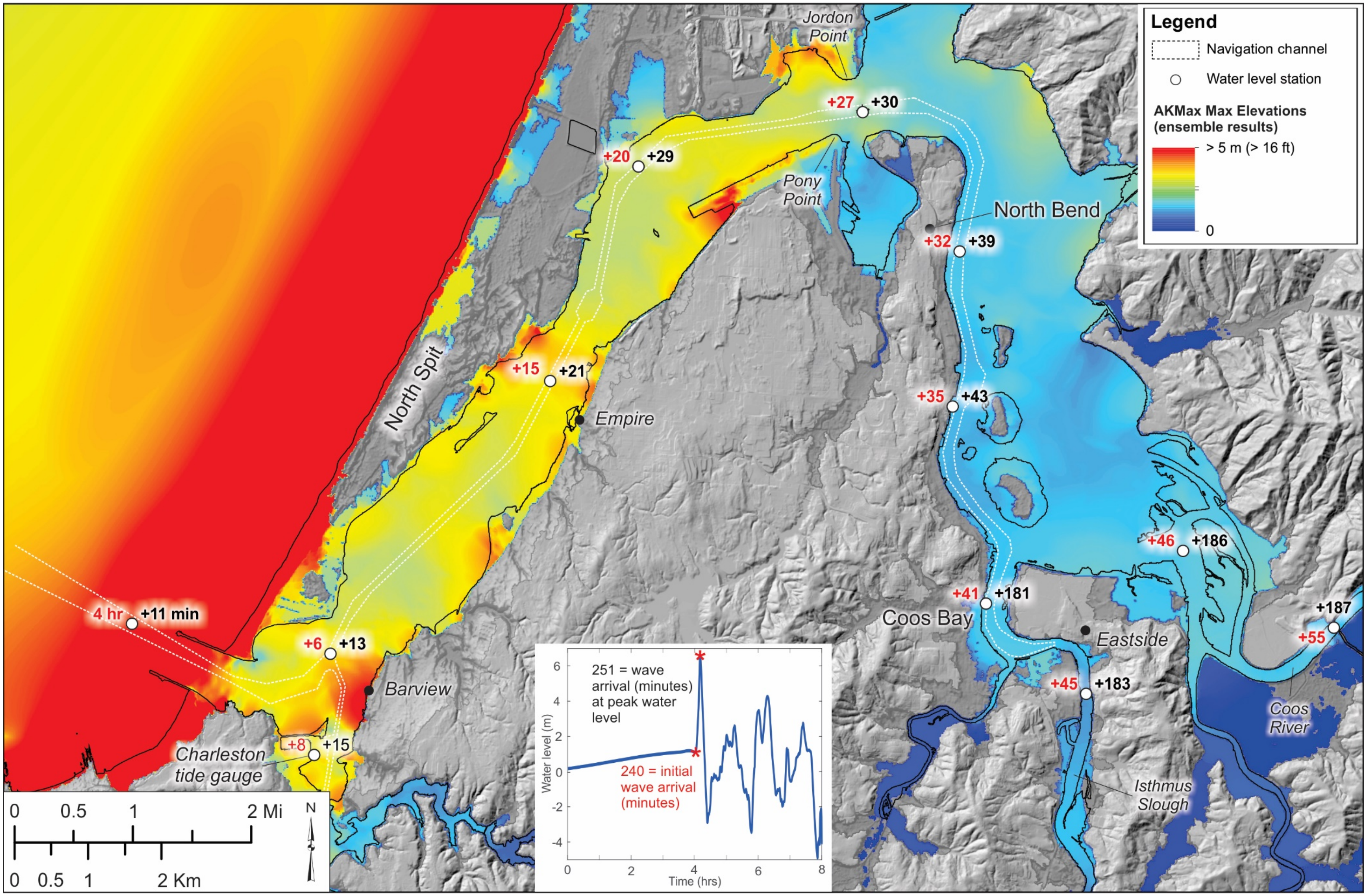
Step 1. Identify the prevailing peak wave period defined for the x-axis.

Step 2. Determine the outgoing (opposing) current velocity (knots).

Step 3. From steps 1 and 2, identify on the y-axis the calculated percentage increase in wave height.

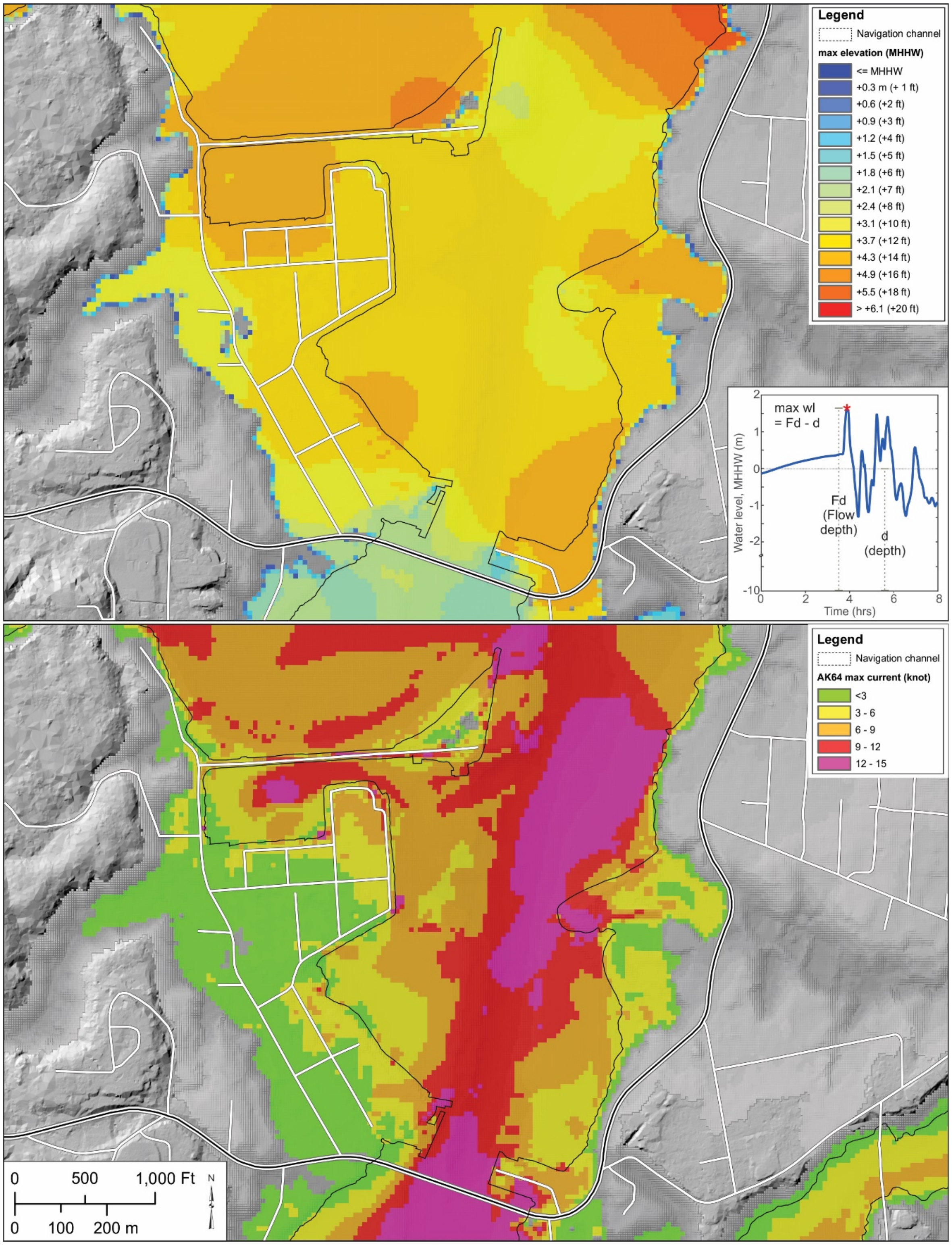
Example: A peak period of 16 sec will yield a 12% (60%) increase in the wave height with a 3 (9) knot opposing current.

Modeled tsunami wave arrival times defined for AKMax (*DISTANT*) for discrete locations along the Coos estuary. Times reported are in minutes and are relative to the initial (4 hr) wave arrival at the MCB. Red numbers correspond to the initial wave arrival (the point at which the water level begins to depart from normal), while the black number reflects the time at which the maximum wave arrives.

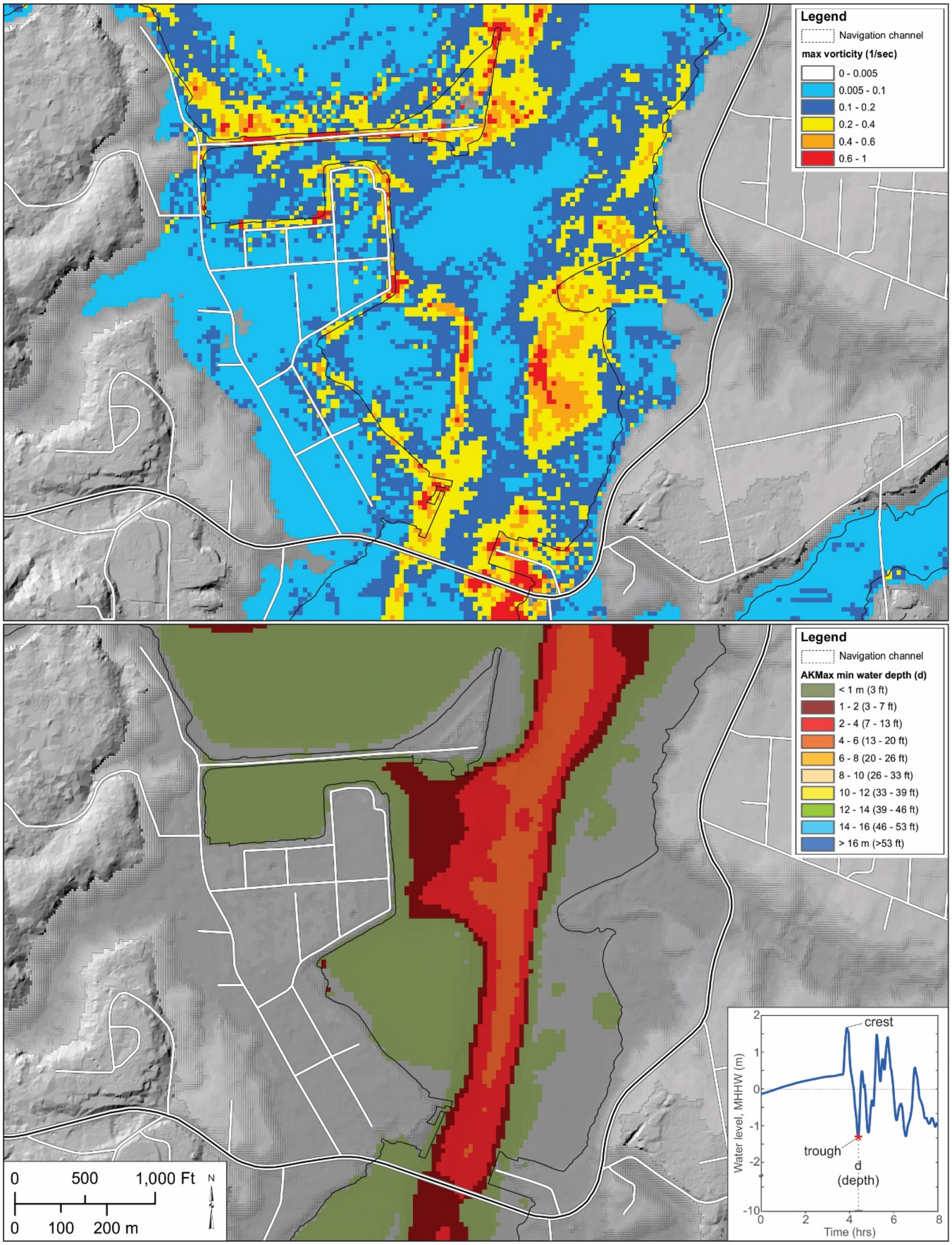


Maritime Guidance for Distant Source Tsunami Events

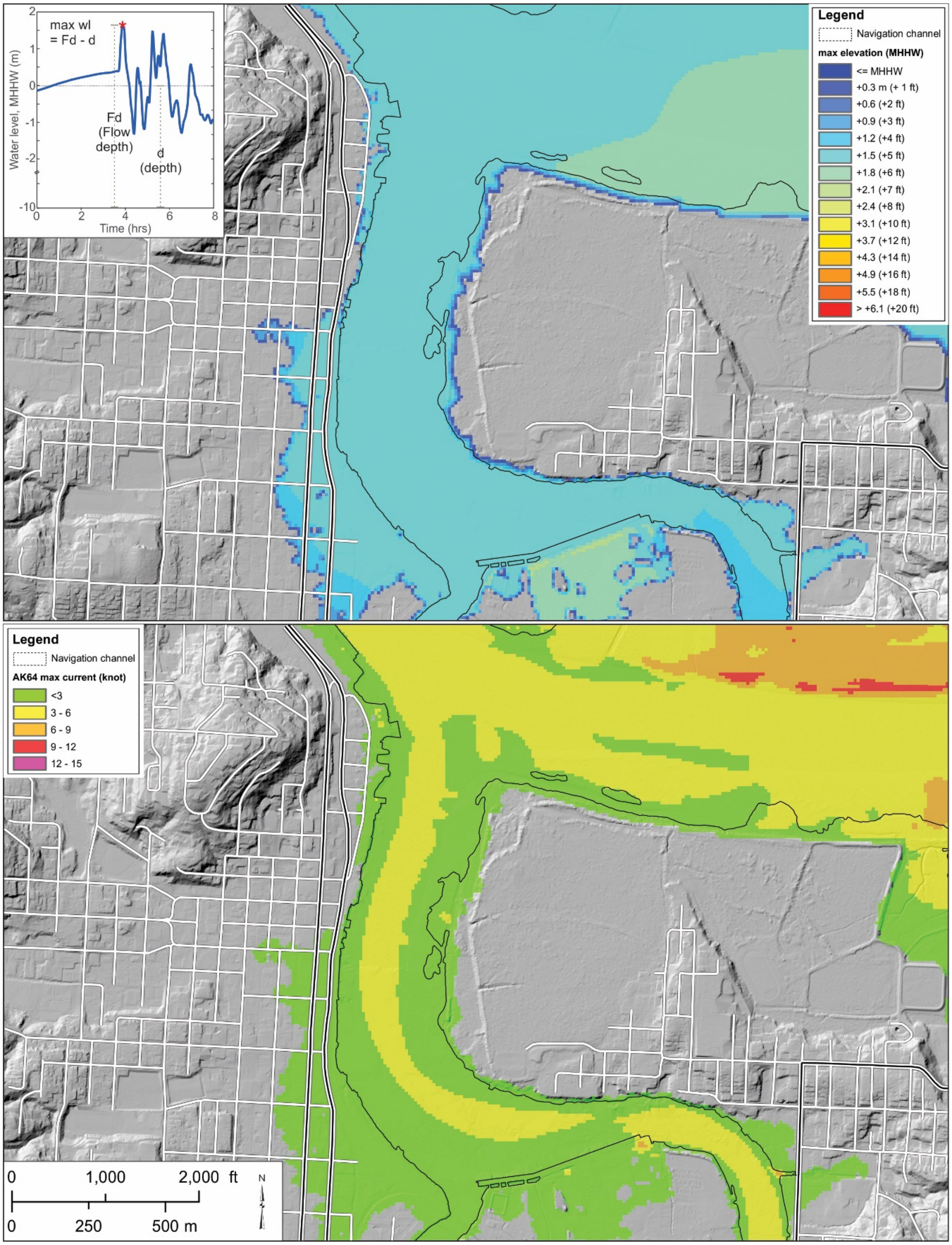
<u>Charleston Marina</u>: <u>Maximum water levels</u> (*top*) and <u>tsunami current velocities</u> (*bottom*) and expected port damage resulting from a maximum-considered *DISTANT* tsunami initiating near the eastern Aleutian Islands (AKMax).



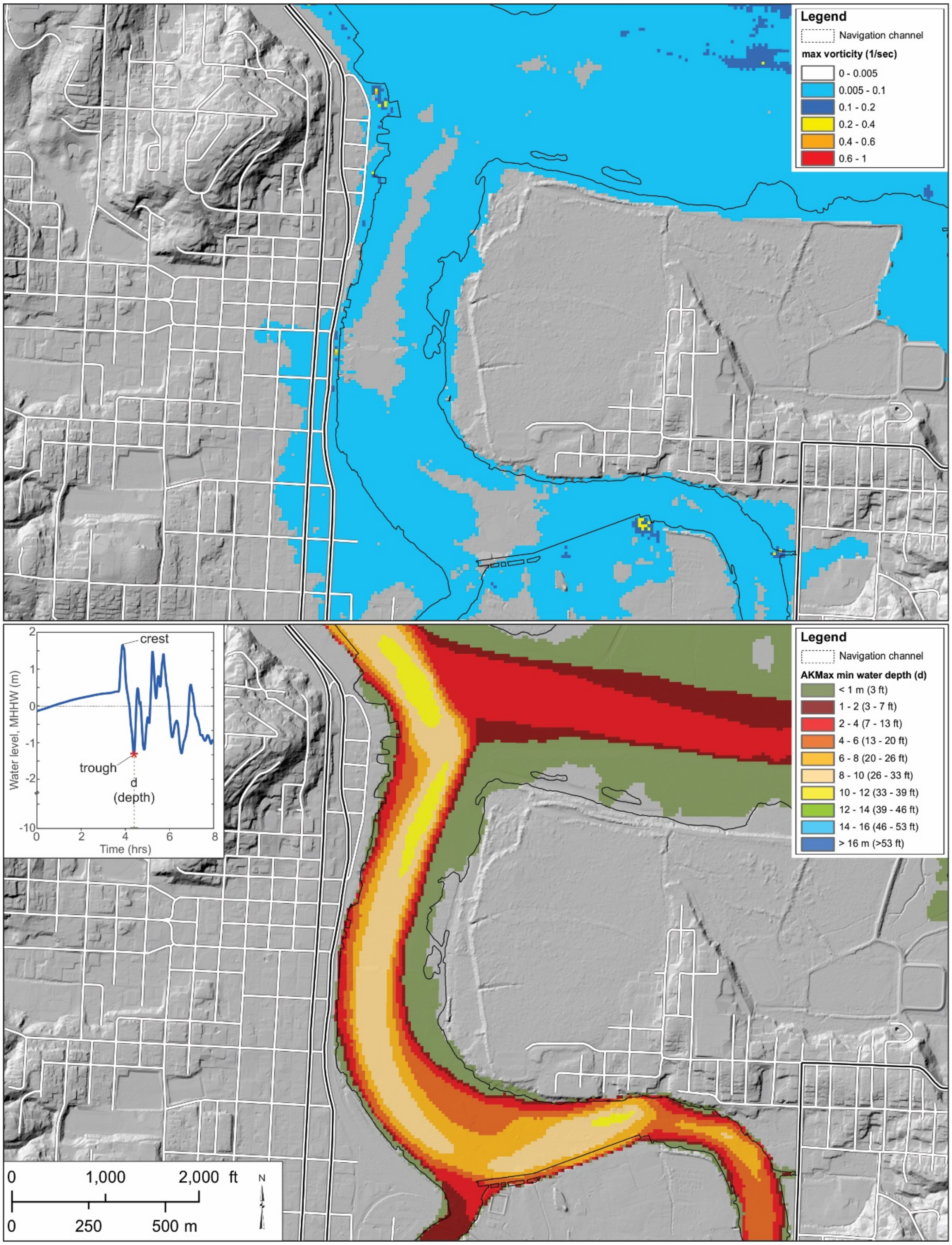
<u>Charleston Marina</u>: Map of the <u>maximum vorticity</u> (*top*) and <u>minimum water depths</u> (*bottom*) generated by a maximum considered *DISTANT* earthquake and tsunami initiating near the eastern Aleutian Islands (AKMax). Top plot is a measure of the potential for rotation (hot colors = strong potential for gyre and whirlpool development), while the bottom shows the expected minimum water depths from the tsunamis.



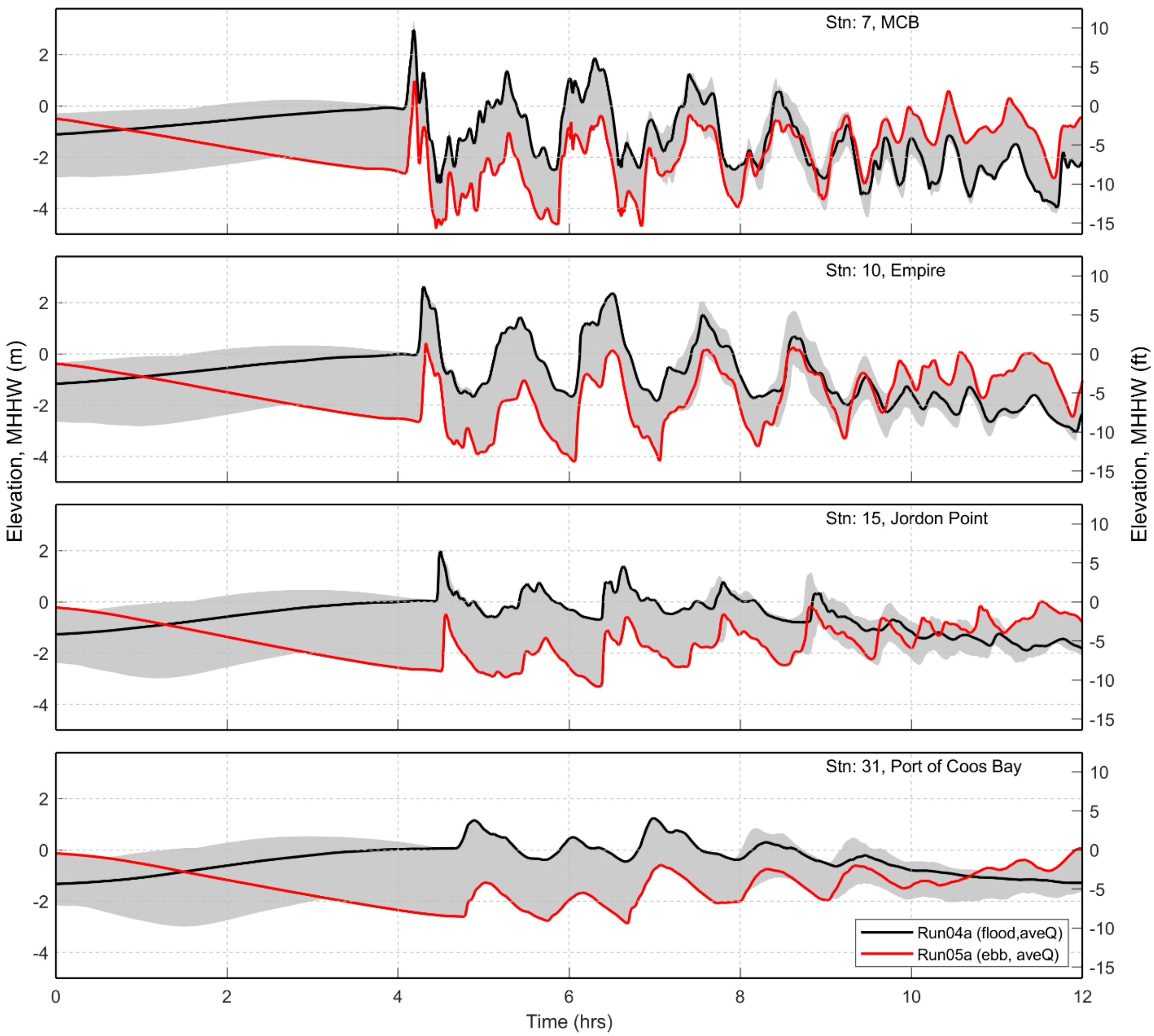
<u>Coos Bay (upper estuary)</u>: <u>Maximum water levels</u> (*top*) and <u>tsunami current velocities</u> (*bottom*) and expected port damage resulting from a maximum-considered *DISTANT* tsunami initiating near the eastern Aleutian Islands (AKMax).



<u>Coos Bay (Upper estuary)</u>: Map of the <u>maximum vorticity</u> (*top*) and <u>minimum water depths</u> (*bottom*) generated by a maximum considered *DISTANT* tsunami initiating near the eastern Aleutian Islands (AKMax). Top plot is a measure of the potential for rotation (hot colors = strong potential for gyre and whirlpool development), while the bottom shows the expected minimum water depths from the tsunamis.



Time histories of tsunami water levels for select sites (top to bottom: MCB, near Empire, Jordon Point, and for Coos Bay (upper estuary)) resulting from a maximum-considered *DISTANT* tsunami (AKMax) initiating near the eastern Aleutian Islands. Simulations shown include both a flood and ebb tide condition. Gray shading defines the envelope of variability of tsunami water levels from all simulations.



Time histories of <u>tsunami current velocities</u> for select sites (top to bottom: MCB, near Empire, Jordon Point, and Coos Bay (upper estuary)) resulting from a maximum-considered *DISTANT* tsunami (AKMax) initiating near the eastern Aleutian Islands. Simulations shown include both a flood and ebb tide condition. Gray shading defines the envelope of variability of tsunami current velocities from all simulations.