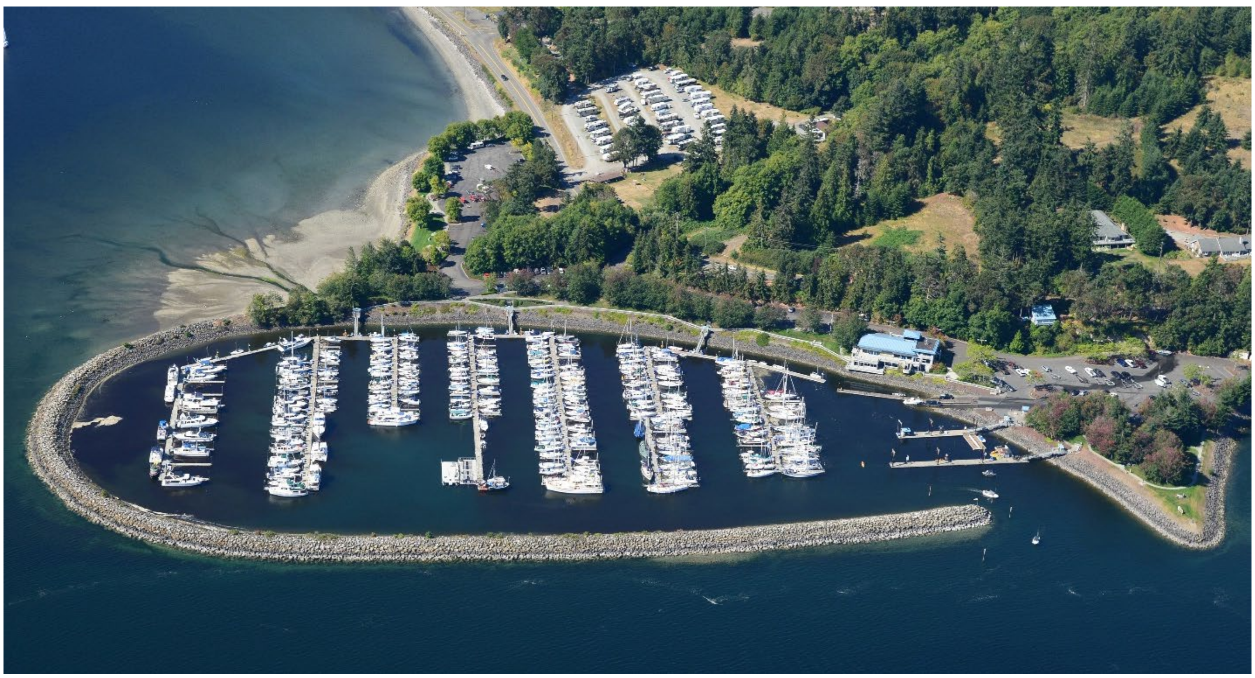
Tsunami Maritime Response and Mitigation Strategy: Port Angeles and John Wayne Marina

Port Angeles and Sequim, Washington

2025



Prepared for:
The Port of Port Angeles

Prepared by:
Washington State Military Department,
Emergency Management Division
20 Aviation Drive, Building 20, MS TA-20.
Camp Murray, WA 98430-5112

This item was funded by NOAA Award #NA24NWSX467G0007-T1-01. This does not constitute an endorsement by NOAA.

Acknowledgements

This strategy was developed as a collaborative effort by the Tsunami Program from the Washington Military Department's Emergency Management Division and the Washington Department of Natural Resources' Washington Geological Survey on behalf of the Port of Port Angeles. The recommendations reached reflect the latest science and are the result of a collaborative effort to consider all points of view by many contributors. We greatly appreciate the participation and support of the following contributors in producing this strategy:

Project Leads:
Ethan Weller – *Tsunami Program Coordinator, Washington Emergency Management Division*
Alex Dolcimascolo – *Tsunami Geologist, Washington Geological Survey*

Primary Stakeholders:
Paul Jarkiewicz – *Executive Director, Port of Port Angeles*
Chris Hartman – *Director of Engineering, Port of Port Angeles*
Scott Hough – *Marine Terminal Manager, Port of Port Angeles*
James Alton – *Airport Manager, Port of Port Angeles*
Justine Chorley – *Emergency Management Coordinator, Clallam County Emergency Management*
Dan Ursino – *Captain (Ret.), U.S. Coast Guard Northwest District*
Brian Meier – *Incident Management and Preparedness Advisor, U.S. Coast Guard Northwest District*

Project Team:
Maximilian Dixon – *Hazards and Outreach Program Supervisor, Washington Emergency Management Division*
Elyssa Tappero – *Tsunami Program Manager, Washington Emergency Management Division*
Dante DiSabatino – *Tsunami Vertical Evacuation Structure Project Manager, Washington Emergency Management Division*
Ellen Chappelka – *Coastal Resilience Specialist, Washington Emergency Management Division*
Daniel Eungard – *Tsunami Geologist, Washington Geological Survey*

Front Cover Photo Credit: Washington Department of Ecology's Shoreline Viewer

Table of Contents

Section 1: An Introduction to Tsunamis

Tsunamis, formidable waves triggered by the sudden displacement of water, pose a significant threat to coastlines across the United States, with Washington State being particularly vulnerable. Local tsunamis generated by nearby seismic activity, such as those from the Cascadia Subduction Zone (CSZ), can swiftly endanger coastal communities, with waves arriving within minutes to hours. Distant tsunamis originating from events in the broader Pacific Ocean basin, most notably from Alaska, present additional response time but still carry substantial risks for Washington.

In Section 1, we provide a comprehensive overview of the key mechanisms and risks associated with tsunamis in the region, shedding light on the potential impacts on coastal areas. This section delves into the natural tsunami warning signs, including ground shaking and ocean abnormalities, while highlighting the pivotal role played by the National Tsunami Warning Center (NTWC) in issuing official alerts. Briefly exploring the parameters used to assess tsunami potential after earthquakes, Section 1 concludes by introducing the various alert messages issued by the NTWC, encompassing warnings, advisories, watches, and information statements.

By serving as a concise yet informative introduction, Section 1 aims to equip readers with a foundational understanding of the factors contributing to tsunamis in Washington State. Emphasizing the significance of both natural and official warning signs, this section sets the stage for a more in-depth exploration of coastal risks and preparedness measures in subsequent chapters.

What are Tsunamis?

Tsunamis are the result of a sudden, large-scale displacement of water. They can be caused by landslides under or into water, large submarine earthquakes, eruptions of coastal volcanoes, meteor impacts into a body of water, and some weather systems. In Washington State the most likely sources of tsunamis are earthquakes and landslides. Earthquakes create tsunamis when the seafloor deforms abruptly and vertically displaces the overlying water column. The displaced water travels outward in a series of waves that grow in intensity as they encounter shallower water near coastlines, as shown in Figure 1. Tsunami wave impacts are greatest in and around ocean beaches, low-lying coastal areas, and bounded water bodies such as harbors and estuaries. The first waves may not be the largest in the series, nor the most destructive. The tsunami's effects include not only rapid flooding of low-lying land, but also dangerously strong currents. As the water travels inland, it scours the ground and picks up large debris, which gives the waves an additional element of destructive force.

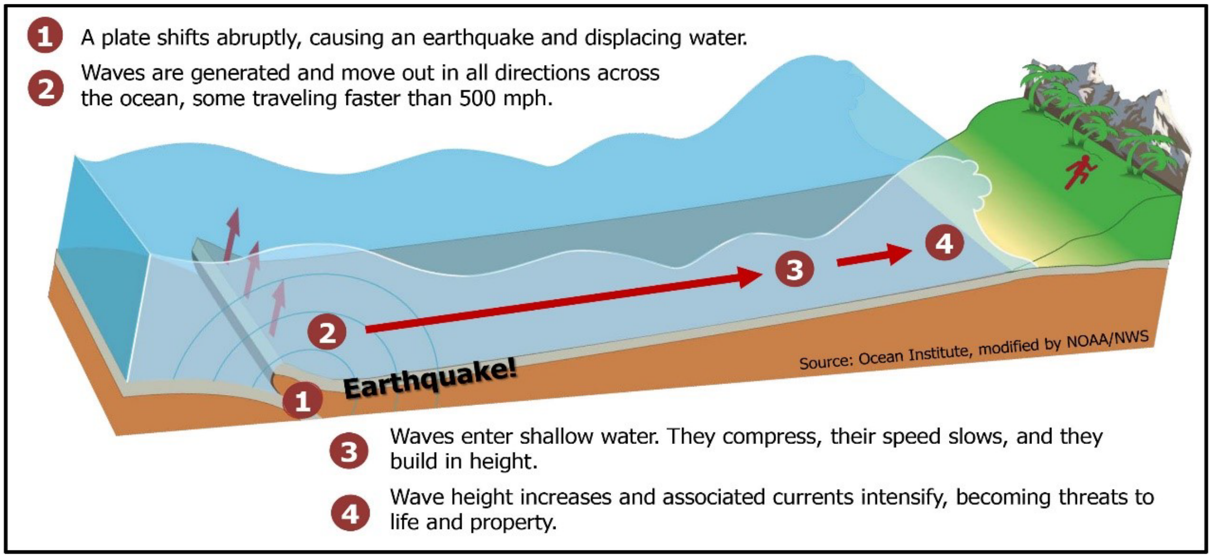


Figure 1: Earthquake generated tsunami diagram (Ocean Institute and NOAA/NWS).

Washington state faces one of the highest tsunami risks in the United States. Over 175,000 residents and visitors are located within Washington's tsunami inundation zone at any given time, along with key military, transportation, and economic infrastructure. The location of the earthquake plays a key role in determining the tsunami travel time to a coastal community, as well as its impact on the community. Washington is at risk from both local source and distant source tsunamis.

Local Source Tsunamis

Figure 2: The wave arrival times of a local CSZ tsunami off the coast of Washington State (WA Geological Survey 2021).

Local source tsunamis are tsunamis for which the first waves arrive at a location in under 3 hours; if caused by an earthquake, you will most likely feel the ground shaking. In Washington, these tsunamis are primarily caused by large underwater earthquakes along the Cascadia Subduction Zone (CSZ) and upper plate crustal faults such as the Seattle Fault Zone (SFZ). The impacts from a local source tsunami can be very high due to the first waves arriving within minutes to a couple hours. The waves can be potentially dozens of feet high with very fast currents, which can cause significant damage to areas within the inundation zone. There is very little time for local authorities to respond and for people to evacuate to high ground.

An earthquake along the CSZ would produce catastrophic tsunami waves that hit Washington's outer coast within 10-20 minutes in some locations (Figure 2). A CSZ tsunami, Washington's greatest local tsunami threat, could cause an estimated 50,000–65,000+ casualties within the first hour (. This represents an estimated 29–37% of the total at-risk population in Washington, not including daytime visitors. A CSZ earthquake and tsunami is estimated to damage 39,000-41,000+ buildings, causing 18–22 billion dollars of damage to buildings. This does not include economic impacts or damage to infrastructure (including ports and marinas), or lifelines. These waves would then hit low-lying parts of the northern inland waters and Puget Sound within two hours or more. The last major earthquake along the CSZ occurred in 1700 and produced large tsunami waves and subsidence along the coast.

Similarly, a large earthquake along the SFZ, such as the estimated magnitude 7.5 event that occurred in 923 C.E., could generate destructive tsunami waves within Puget Sound. Strong currents and water level changes would continue for 12-24 hours or longer. These waves would inundate coastal areas within minutes, with strong currents and significant water level changes persisting for hours. The SFZ scenario also poses unique risks to the densely populated and industrialized areas around central Puget Sound, where the proximity to the fault could exacerbate both shaking impacts and tsunami hazards. Washington has other crustal faults scattered throughout the Puget Sound and Salish Sea with unknown tsunamigenic potential.

With both the CSZ and crustal faults, earthquake shaking could trigger landslides that generate additional localized tsunamis, compounding the immediate impacts. Aftershocks of sufficient size may also produce secondary tsunamis in the days, weeks, and months following major CSZ earthquakes.

Distant Source Tsunamis

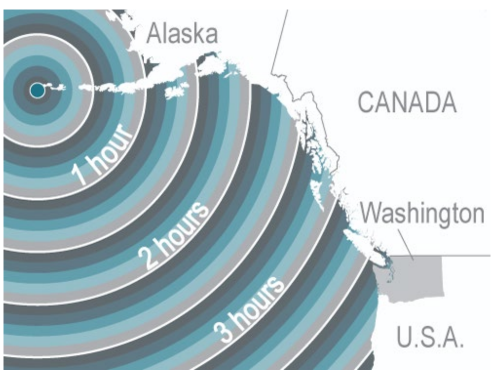


Figure 3: The wave arrival times of a distant tsunami originating off the coast of Alaska (WA Geological Survey 2021)

Distant source tsunamis are tsunamis for which the first waves arrive at a location in over 3 hours; if caused by an earthquake, you will not feel the ground shaking. These tsunamis are most frequently caused by large underwater earthquakes in other parts of the Pacific Ocean basin. The impacts from a distant source tsunami are lower than from a local source tsunami because it takes longer for the tsunami waves to arrive, the waves are usually not as high, and the speed of the currents is usually slower. This varies greatly depending upon the location and magnitude of the earthquake that generates the tsunami. For example, tsunami waves originating in or near Japan would take 9-10 hours to arrive on Washington's outer coast, which provides much more time for responsive actions than a tsunami originating off the coast of Alaska, for which waves would arrive in Washington within 3.5-4 hours.

Alaska is home to the Alaska-Aleutian Subduction Zone and is Washington's highest risk for a distant source tsunami. Depending on its location, a magnitude 9.2 earthquake off the coast of Alaska, like the Great Alaskan Earthquake of 1964, could potentially generate 20+ foot high tsunami waves off Washington's coast that could last 12-24 hours or longer. This has the potential to cause widespread damage along Washington's outer coast. People located in Washington would not feel the earthquake and must rely on other alert methods to know when a distant source tsunami is on the way.

Natural Tsunami Warning Signs

You may not receive an official tsunami alert for either a local or distant source tsunami. You therefore need to be able to recognize the natural warning signs of a tsunami and respond immediately when you experience any one of them:

- If you are ONSHORE, you might:
    - Feel strong ground shaking (local source tsunami only)
    - Hear a loud roar from the ocean
    - See water rapidly receding, possibly exposing the sea floor
    - See water surging towards the shore faster than any tide
- If you are OFFSHORE on a vessel, you might:
    - Feel shaking through the hull of your vessel (local source tsunami only)
    - See a rapid or extreme shift in currents and simultaneous changes in wind wave heights

Official Tsunami Alerts

Tsunami alerts for Washington State originate from the National Oceanic and Atmospheric Administration's (NOAA) National Tsunami Warning Center (NTWC) in Palmer, Alaska. NTWC detects, locates, sizes, and analyzes earthquakes throughout the world 24 hours a day. NOAA is the authorized agency solely responsible for determining a region's appropriate tsunami alert level based on historical and preliminary earthquake event data, as well as preparing and issuing tsunami bulletins in which the alert level information is included. Tsunami alerts and event information for Washington are disseminated by the NTWC, National Weather Service (NWS), United States Coast Guard (USCG), the Washington State Emergency Operations Center (SEOC), Tribes, and local jurisdictions. Tsunami alerts require immediate response due to the urgent nature of the event so the more alert methods you are signed up for, the better your chance of receiving a tsunami alert in a timely manner.

Official tsunami alerts are most important for distant tsunamis and can also be useful for people farther from the origin of a local source tsunami. For those individuals near the source, such as people on the outer coast for a CSZ tsunami, the impacts could occur too quickly to receive official alerts. Ground shaking could also disable the communication systems necessary for sending and receiving official alerts. Individuals on the coast should be prepared to recognize the natural warning signs and act on them immediately.

Tsunami Alert Levels

NTWC will issue a tsunami alert based on seismic data analysis and forecasted wave amplitude. NTWC issues tsunami warnings, advisories, watches, and information statements. Each has a distinct meaning relating to recommended protective actions and local emergency response as summarized in Figure 4. The full definition of each message is given below:

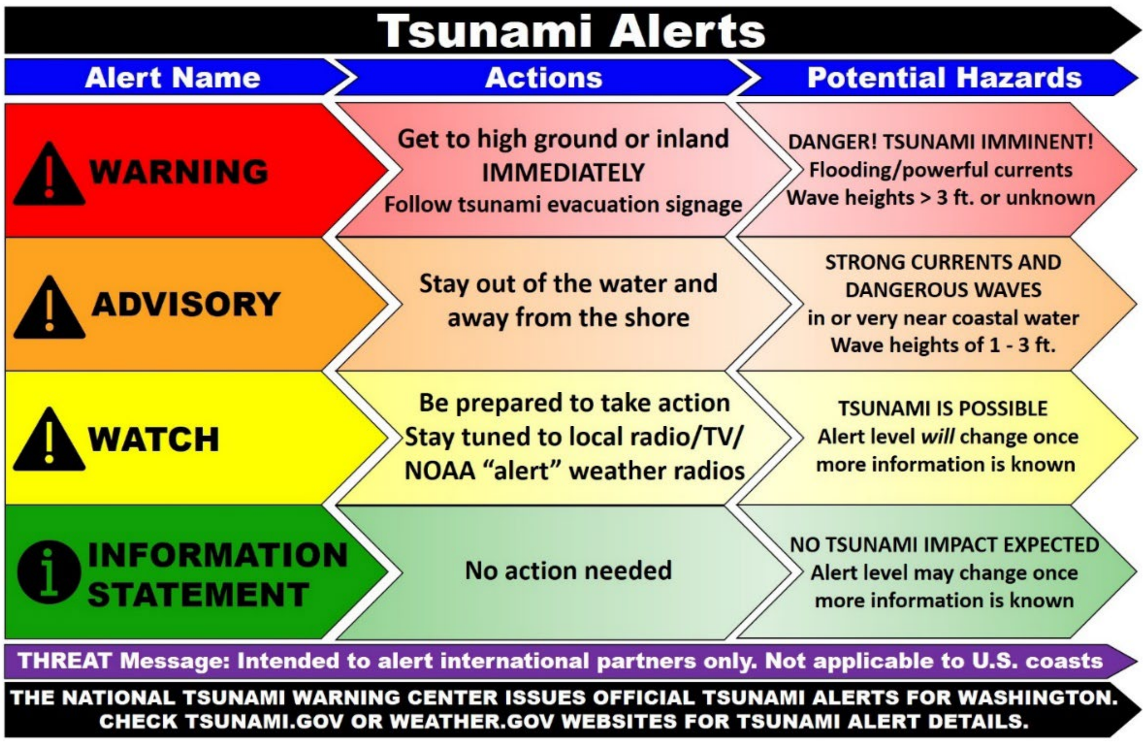


Figure 4: Official tsunami alert levels, associated effects, and protective actions to be taken (WA EMD).

Tsunami Warning

A tsunami warning is issued when a tsunami with the potential to generate widespread inundation is expected, imminent, or occurring. Warnings alert the public that dangerous coastal flooding accompanied by powerful currents is possible and may continue for several hours after initial arrival. Warnings alert emergency management officials to take action for the entire tsunami hazard zone. Appropriate actions to be taken by local officials may include the evacuation of low-lying coastal areas and the repositioning of ships to deep waters when there is time to safely do so. Warnings may be updated, adjusted geographically, downgraded, or canceled. To provide the earliest possible alert, initial warnings are normally based only on seismic information.

Tsunami warnings are typically issued following coastal earthquakes with a magnitude 7.1 or greater for U.S. and Canadian Atlantic and Gulf coasts, and magnitude 7.9 or greater for all coasts along the Pacific Ocean and Caribbean Sea. Tsunami height also affects which alert level is selected. In general, the tsunami warning centers issue a tsunami warning if the forecast or observed tsunami height exceeds 3.3 feet (1.0 meter) or the impact is unknown.

Tsunami Advisory

A tsunami advisory is issued when a tsunami with the potential to generate strong currents or waves dangerous to those in or very near the water is expected, imminent, or occurring. The threat may continue for several hours after initial arrival, but significant inundation is not expected for areas under an advisory. Appropriate actions to be taken by local officials may include closing beaches, evacuating harbors and marinas, and the repositioning of ships to deep waters when there is time to safely do so. Advisories are normally updated to continue the advisory, expand/contract affected areas, upgrade to a warning, or cancel the advisory. In general, the tsunami warning centers issue a tsunami advisory if the forecast or observed tsunami height exceeds about 1 foot (0.3 meter) or is less than 3.3 feet (1.0 meter)

Tsunami Watch

A tsunami watch is issued to alert emergency management officials and the public of an event which may later impact the watch area. The watch area may be upgraded to a warning or advisory, or canceled, based on updated information and analysis. Therefore, emergency management officials and the public should prepare to take action and tune into official sources for updated information. Watches are normally issued based on initial seismic information but require additional information to confirm that a tsunami is underway. Typically, tsunami watches are issued when there is an anticipated wave and wave arrival is outside of a 3-hour window.

Tsunami Information Statement

A tsunami information statement is issued to inform that an earthquake has occurred or that a tsunami warning, advisory, or watch has been issued for another section of the ocean. In most cases, information statements are issued to indicate there is no threat of a destructive basin-wide tsunami and to prevent unnecessary evacuations as the earthquake may have been felt in coastal areas. Information statements may indicate for distant regions that a large event is being evaluated and could be upgraded to a warning, advisory, or watch.

Receiving Tsunami Alerts

NTWC alerts can be received in several different ways. Tsunami.gov is a website run by NOAA that shows recent earthquakes on a world map and a list of the last 40 alert messages that have been issued, as well as a database of all messages issued in the past. While this website is a useful tool, it can suffer issues during high traffic times, such as during a tsunami event. However, there are other ways to have tsunami alert messages delivered to you as they are released by the NTWC. One of the most important things to remember about alerting is that you should have multiple methods of receiving alerts to ensure important alerts are received. Keep in mind that some forms of receiving alerts may not work when at sea or in remote locations. For this reason, marine vessel owners should be sure their vessel is equipped with a marine radio as well as a NOAA weather radio to ensure a viable form of receiving alerts even while at sea. Tsunami alerts can be received by officials and the public in several ways:

- NOAA Weather Radio
- InteractiveNWS (iNWS)
- All Hazard Alert Broadcast (AHAB) Sirens (onshore only)
- Marine Radios
- Vessel Traffic Service (VTS)

You can also learn more about how to receive alerts for tsunamis and other types of hazards at mil.wa.gov/alerts.

Section 2: Tsunami Maritime Hazards

Section 2 explores tsunami hazards for mariners and vessels, highlighting risks in coastal navigation. It outlines potential consequences for maritime infrastructure and marine vessels, including severe water-level fluctuations, capsizing, strong currents, eddies/whirlpools, collision risks, and dangerous debris. Recognizing the correlation between current velocity and damage, specific thresholds for potential harm are also discussed, considering factors such as the age and maintenance of infrastructure.

The section introduces actionable tsunami alert levels for maritime communities, stressing the need for clear advisories and warnings. It emphasizes monitoring and responding to alerts from the National Tsunami Warning Center, underscoring the importance of preparedness in the maritime community.

Concluding with practical guidance, the section addresses mariners' response strategies during local and distant tsunamis, covering vessel preparation, evacuation, and considerations for those at sea. Historical lessons learned provide valuable insights into tsunamis' unpredictable nature and the critical role of informed decision-making for maritime safety.

Tsunami Hazards for Mariners and Vessels

Figure 5: Damage in Crescent City, California, from the 2011 Japan tsunami, about 10 hours after the initial earthquake. (Craig Miller/KQED).

Figure 6: Standing tsunami bore wave in Sunaoshi River, Miyagi Prefecture, Japan 2016. (Miyagi Prefectural Police / Kyodo / Reuters, 2016).

Tsunamis pose many significant hazards for boaters and their vessels. Sudden large fluctuations in water level can quickly swamp unprepared vessels and/or wash them onto shore. In shallow areas these fluctuations can also ground vessels on the sea floor when water rapidly recedes, only to be overtopped by water when the next wave arrives (Figure 5). These incoming and receding surges of water can also create large tsunami bores, which are powerful surges of water resembling a wall that move upstream in rivers and estuaries during a tsunami. Tsunami bores can capsize boats and pose a danger to navigation (Figure 6).

Tsunamis can create strong and dangerous currents that pose serious risk to vessels and maritime facilities, with speeds often exceeding 9 knots above normal currents. These currents can be amplified by the geography and bathymetry of the surrounding area. Narrow waterways and areas around islands are especially dangerous, as well as areas where water is shallower. These strong currents can lead to the formation of large whirlpools and eddies (Figure 7) which cause vessels to become trapped and unable to escape under their own power. These complex, fast-moving tsunami waves can quickly change direction, making them extremely unpredictable. This creates increased risk in areas of waterway congestion that can cause vessels to crash into each other. Tsunamis also generate extensive debris and hazardous materials that create additional risk of collisions and other secondary hazards such as fires and chemical exposure (Figure 8).

Figure 7: Whirlpools forming off Japan's coast after the 2011 tsunami. (Yoiumri / Reuters).

All the above risks exist inside harbor and port areas, not just in the open water. Extreme water level fluctuations during a tsunami can force docks to overtop pilings, become detached from the shore or sea floor, or break apart in sections (Figure 9). Vessels can ground when water recedes, leaving them vulnerable to incoming waves. Large, deep keeled vessels can experience strong enough drag to rip them from their moorings or lift them on top of docks or the shore (Figure 10). Narrow entrances to harbors can amplify current speeds and cause water to move in unexpected directions. The confined nature and amount of infrastructure and vessels in harbors can lead to a massive amount of debris moving through the area, creating dangerous conditions for mariners and their vessels. All these hazards may persist for 12-24 hours or more.

Figure 9: Tsunami debris in the water after the 2011 tsunami in Ishinomaki, Japan (Koyodo News / AP).

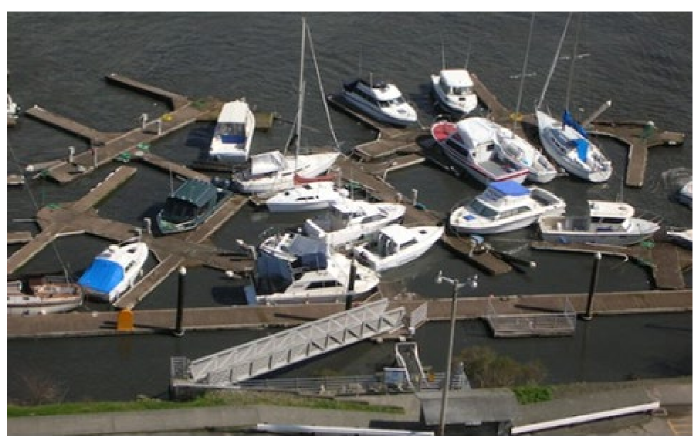


Figure 8: Docks broken from Japan 2011 distant tsunami in Brookings, OR (USCG / Group Air Station North Bend).

Figure 10: Ship lifted on to land and grounded by tsunami waves in Japan (Telegraph.co.uk/EPA).

Summary of Tsunami Hazards That Can Impact Vessels

- Severe water-level fluctuations
  - Docks overtopping piles as water level rises
  - Vessels washed onto shore and grounded
  - Grounding of vessels as water level suddenly drops
  - Capsizing from incoming surges (bores), complex coastal waves, and surges hitting grounded vessels
- Strong and unpredictable currents that can change direction quickly
  - Eddies/whirlpools
  - Drag on large-keeled vessels
  - Collision with other vessels, docks, and debris
- Dangerous tsunami conditions can last 12-24 hours or longer after the first wave arrives, creating challenges for boaters who take their vessels offshore

Current Velocity, Areas of Dangerous and Unpredictable Currents, and the Relationship Between Current Speed and Damage

Current Speed	Damage Type
0 Knots	No Damage
>0-3 Knots	No Damage: • Small buoys moved
3-6 Knots	Minor/Moderate damage: • Docks/small boats damaged • Large buoys moved
6-9 Knots	Moderate/Major Damage: • Damage to docks and boats • Mid-sized vessels off moorings
>9 knots	Major Damage: • Significant damage to docks and boats • Large vessels off moorings
>>9 Knots	Complete Destruction: • Widespread damage to all maritime infrastructure and vessels of all types

Figure 11: Current speeds and expected damage (Pat Lynett, 2014). Colors represent current speed models shown later in the document.

Tsunami damage inside harbors can be directly attributed to strong currents. Tsunami currents are in excess of existing or 'normal' currents in the area, meaning their speed is added on top of the base, or normal tidal current speed. Damage varies based on the current speed and direction, as well as the age and location of docks and vessels, yet some generalities about the relationship between tsunami currents and damage can be noted (Figure 11).

One such generality is that the faster the current speed, the greater the chance and severity of damage. Beginning at tsunami current speeds of ~3 knots (1 knot = 1.15 miles per hour) above normal there is risk of minor to moderate damage to docks and smaller boats. Beginning at ~6 knots the risk increases to moderate to major damage and could impact larger vessels. Once tsunami current speeds reach ~9 knots or greater the risk of complete destruction becomes extreme for all maritime infrastructure and vessels in the area.

It should be noted that the 3-6-9 knot current speed thresholds are appropriate for newer (<30-40 years old) and well-maintained docks and harbor infrastructure. For estimating damage to older (>40-50 years old) and less maintained docks, it may be more appropriate to use current speed thresholds of 2-5-7 knots (Pat Lynett, 2014).

General Guidance on Response to a Local Tsunami

Because you may have only minutes to act before tsunami waves arrive, it is important to have an emergency plan for your vessel and at least 3 days of food, fuel, and water stored onboard. Be sure to include a quick way to release commercial fishing gear so that your boat is not dragged down by sudden increased currents.

During the tsunami

If you are on land or tied up at the dock:

- Leave your vessel and head inland to high ground on foot as soon as possible. You do not have time to save your vessel in this situation and could die trying to do so.

If you are on the water but near shore (outer coast) or on the inner coast of Washington:

- Use your best judgement to decide between the following options: safely beach/dock your vessel and evacuate on foot to high ground or get to minimum offshore safe depth of 30 fathoms (180 feet).
    - Attempting to beach your vessel could be challenging and dangerous due to wave conditions, water levels, or the presence of bars. It is easy for a boat to run aground or capsize before reaching the shore only to be swept up by the coming tsunami wave.
    - However, if you can safely beach or dock your vessel and evacuate to high ground before the tsunami arrives, this is your best option. If that is not possible, head to deep, open water as quickly as possible and stay away from other vessels.

If you are on the water and not near the shore on the outer coast of Washington:

- Aim to get to 100 fathoms (600 ft) or nearest and deepest possible water. Stop fishing operations immediately, freeing the vessel from any bottom attachments (cut lines if necessary). Keep in mind the following:
    - Proceed as perpendicular to the 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 any other vessels to avoid collisions
- At 100 fathoms (600ft) or deeper: If you are already at a location where the water depth is 100 fathoms or deeper, you are relatively safe from the impacts of a tsunami.

After the tsunami

- If you are at 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 the USCG and local authorities. Local ports could sustain heavy damage from a local tsunami and may

not be safe for days, weeks or months due to the presence of debris and hazardous materials.

- 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 the USCG about your role in response and recovery.

Lessons Learned from Local Tsunamis: Stories from the March 28, 1964, Alaska Tsunami, the 2004 Indian Ocean Tsunami, and the March 11, 2011 Tohoku Tsunami in Japan

The first wave is not always the largest for tsunamis. At Kodiak, Alaska during the 1964 tsunami the first wave was 3.4 m (11 ft) at the nearby Naval Air Station, while the fifth wave was 7.6 m (25 ft) at high tide (Lander, 1996). The tsunami arrived within 10 minutes of the earthquake. In Valdez, Alaska, the tsunami wave hit the harbor, wiping out the entire fishing fleet. The waves were strong enough to travel two blocks inland, causing widespread devastation. More than two dozen people lost their lives because they were standing at the pier.

A couple out snorkeling in Phi Phi Lei, Thailand, managed to survive as their boat was in deep water when the waves arrived and headed to deeper water just in case. They saw longtail boats closer to the shoreline snap into pieces and sink quickly and had to wait out in the open water waiting for advice on what to do next. They ended up staying on the boat overnight so that help could come out to meet them.

In Japan, a local fisherman decided to take his boat out to deep water and beat the incoming waves. When faced with a wall of water “four times bigger” than anything else he had ever experienced, he described the moment he came face-to-face with the wave: “I talked to my boat and said you’ve been with me 42 years. If we live or die, then we’ll be together…”

The primary lesson in local tsunamis is that there is INSUFFICIENT time for harbor personnel or vessel captains/owners to take any response actions (i.e., remove vessels offshore or out of the harbor) prior to the arrival of the tsunami. Evacuation inland to high ground out of the tsunami inundation zone was the only possible action. Vessel captains and owners should head to deeper water if that is their only safe course of action before waves arrive. Once at deeper water, it may take hours before it is safe to return to impacted areas.

Actionable Tsunami Alert Levels

Tsunami warnings and advisories are the two alert levels which require immediate action by maritime communities. For both advisory and warning level incidents, it is important that clear and consistent directions are provided to the entire boating community and to waterfront businesses.

Tsunami Warnings	Tsunami Advisories
Tsunami wave heights could exceed 3 feet (1 meter). Dangerous coastal flooding accompanied by powerful currents is possible.	Tsunami wave heights of 1 to 3 feet (0.3 to 1 meter) are expected. Strong currents or waves dangerous to those in or very near the water are possible.
SIGNIFICANT tsunami currents and damage are possible to all maritime infrastructure and vessels.	SIGNIFICANT tsunami currents and damage to maritime infrastructure and vessels are possible near harbor entrances or narrow constrictions.

General Guidance on Response to a Distant Tsunami (Tsunami Advisories and Warnings)

During the tsunami (tsunami advisory)

- *If you are onshore:*
  - Ensure you are wearing a personal floatation device.
  - Secure and strengthen all mooring lines throughout harbor, specifically areas near entrances or narrow constrictions.
  - Evacuate from all structures and vessels in the water before first waves are expected to arrive.
- *If you are on the water:*
  - Aim to get to 30 fathoms (180 ft) or nearest and deepest possible water.
  - Prepare for heavy seas and currents. Maintain extra vigilance and monitor VHF Channel 16 (158.000 MHz) for Urgent Marine Information Broadcast from the US Coast Guard.
  - Monitor VHF FM Channel 16 (158.000 MHz) and the marine WX channels for periodic updates of tsunami and general weather conditions; additional information will be available from NOAA Weather Radio.
  - It is not recommended that captains take their vessels offshore during a tsunami because they could put themselves at greater risk of injury. However, if they do decide to go offshore, they should have the experience, fuel, and supplies to stay offshore for more than 24 hours. Damage to dock infrastructure may limit their ability to return to the same dock.
  - If conditions do not permit, dock your boat and head inland to high ground.

After the tsunami (tsunami advisory)

- Mariners at sea should monitor VHF Channel 16 (158.000 MHz) for US Coast Guard Safety Marine Information Broadcasts regarding conditions and/or potential restrictions placed on navigation channels and entrances to harbors.
- 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. Port authorities will not allow the public to reenter structures and vessels in the water until the advisory is cancelled and conditions are safe.

During the tsunami (tsunami warning)

- *If you are onshore (OUTER COAST ONLY):*
  - Vessels considering leaving the harbor and heading to sea should 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 multiple days at sea
    - If you do not have time to accomplish your goal, you should not make the attempt.
    - REMEMBER: There may be road congestion getting to the marina. 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 (158.000 MHz) and use extreme caution. NEVER impede another vessel.
  - 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 tsunami; then exit the tsunami inundation zone.
  - It is not recommended that captains take their vessels offshore during a tsunami because they could put themselves at greater risk of injury. However, if they do decide to go offshore, they should have the experience, fuel, and supplies to stay offshore for more than 24 hours or possibly have the resources to travel to a different port if extensive damage occurs to their home port.
- *If you are on the water:*
  - Prepare for heavy seas and currents. Maintain extra vigilance and monitor VHF Channel 16 (158.000 MHz) for possible Urgent Marine Information Broadcast from the US Coast Guard.
  - Monitor VHF FM Channel 16 (158.000 MHz) and the marine WX channels for periodic updates of tsunami and general weather conditions; additional information will be available from NOAA Weather Radio.

   - If conditions do not permit, dock your boat and head inland to high ground.

After the tsunami (tsunami warning)

- Mariners at sea should monitor VHF Channel 16 (158.000 MHz) for possible US Coast Guard Safety Marine Information Broadcasts regarding conditions and/or potential restrictions placed on navigation channels and entrances to harbors.
- 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 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, 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.

Lessons Learned in Distant Tsunamis: Stories from Northern California from the March 11, 2011 and the 1964 Alaska tsunami

Prior to the arrival of the March 11, 2011 Japanese tsunami in Crescent City, California, many commercial fishing boats headed to sea. Once the tsunami hit and they realized they were unable to return to Crescent City Harbor due to its damage, 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 of the captains had never been to Humboldt Bay and some were running single-handed as they did not have enough time to round up crew. The captains 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, when the waves coincided with high tide.

One captain reported that to safely navigate the waves coming in and out, he had to keep turning around his vessel for hours on end until the waves were small enough for his vessel to handle. After he made it back onshore, he exclaimed that given the choice, he would never decide to take his vessel out in a tsunami again.

In the 1964 Alaska tsunami, mariners off the coast of Crescent City made it nearly impossible to navigate through the water. Some mariners had to abandon their vessels or try and dock offshore in order to swim to the shoreline.

The primary lesson is: if you plan to take your boat offshore during a tsunami, only do so if you have the experience, supplies, and fuel to stay offshore or travel long distances to other harbors because dangerous tsunami activity could last for more than 24 hours and damage within harbors might prevent reentry.

Mariner Considerations During Both Local and Distant Tsunamis

Mariners and vessel captains will need to take into consideration many factors if they are at sea during a tsunami. Captains will need to decide whether to remain at sea and search for safer locations (deep water away from other vessels and debris) to attempt to ride out the tsunami or to instead return to shore, secure their vessel, and evacuate to high ground. These decisions largely depend on the type of tsunami and these 5 major considerations:

- How much time before waves arrive
- How much time it will take to reach a safe location
- The preparedness and readiness of the vessel and its captain
- The weather conditions at sea, as they could be as dangerous as the tsunami itself
- The congestion on roads and boat ramps

Within those considerations, it’s important to know:

- the distance to shore or deep water (100 fathoms or 600-foot depth)
- the skill level of the captain and crew
- the vessel speed and capability
- the draft of the vessel
- the number of provisions, fuel, and equipment on board
- tide stage and conditions on the sea
- whether the vessel has adequate communication with other nearby vessels and authorities on shore (Figure 13)

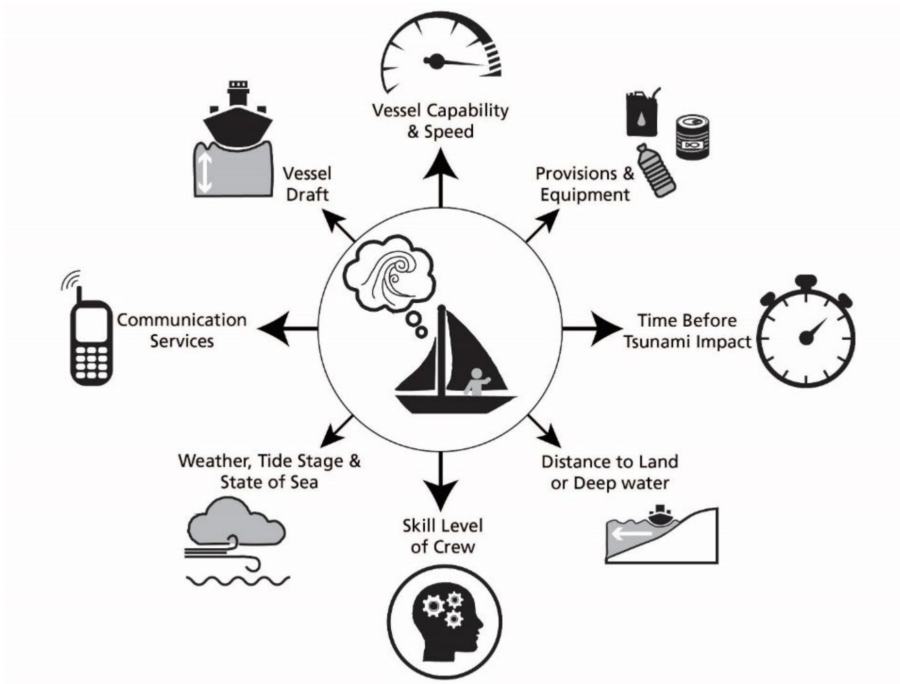


Figure 12: Considerations for boaters who are already offshore during a tsunami (WA Geological Survey).

When faced with the decision of whether to remain at sea or return to shore during a tsunami, safety must always be the top priority. Mariners and vessel captains should carefully consider the time before waves arrive, the feasibility of reaching a safe location, the vessel's preparedness, weather conditions, and potential congestion on roads and boat ramps (Figure 12). However, in situations of uncertainty or doubt, it is strongly advised to err on the side of caution and seek shelter on shore. Prioritizing the safety of all individuals on board and minimizing risks should guide decision-making processes during such critical moments at sea.

Section 3: Tsunami Maritime Hazard and Risk Assessment for Port Angeles Harbor and Sequim Bay

Section 3 focuses on the specific tsunami maritime hazards and risks to the Port Angeles Harbor and Sequim Bay, first by introducing baseline information about the harbor and then establishing the regional boundaries of site-specific tsunami modeling conducted for this strategy. The potential impact of tsunamis on critical maritime infrastructure is then assessed using topography, bathymetry, and coastal dynamics. Detailed tsunami modeling results offer valuable insights into the potential impact of tsunamis on the maritime infrastructure within each area.

Figure 13: The Port Angeles waterfront and downtown areas, highlighting the area's commercial and industrial roots. (WA Ecology, 2016)

Introduction to Sequim Bay, the Port Angeles Harbor and City of Port Angeles

Anchored along the Strait of Juan de Fuca, Port Angeles Harbor is protected by the Ediz Hook, a naturally formed spit that has undergone beach nourishment to maintain its effectiveness. The U.S. Coast Guard Station and Air Station, and Puget Sound Pilots Station occupy the eastern half of Ediz Hook and are inaccessible to the public. The Port of Port Angeles Harbor has a deep maritime history that acts as a critical economic engine for the City of Port Angeles and surrounding Clallam County area. The seven terminals owned by the port contribute significantly to the surrounding community, bringing in approximately $213.1 million in direct business revenues from sales of goods and services. The operations at the industrial properties and marine terminals account for 70% of the total jobs and revenues generated by the port.

Since the establishment of a port district in 1922, the development and growth of the port has coincided with the establishment of the surrounding community. As a critical shipping hub, the Port of Port Angeles historically was responsible for leasing land to businesses that handled and processed wood products. Their portfolio has greatly expanded over the past 75 years and now includes repair, manufacturing, aviation components, commercial diving and restaurants, among many other essential commercial businesses.

Of the seven terminals along the Port Angeles waterfront, five are currently in operation: terminals 1, 2, 3, 4, and 7 (Figure 14).

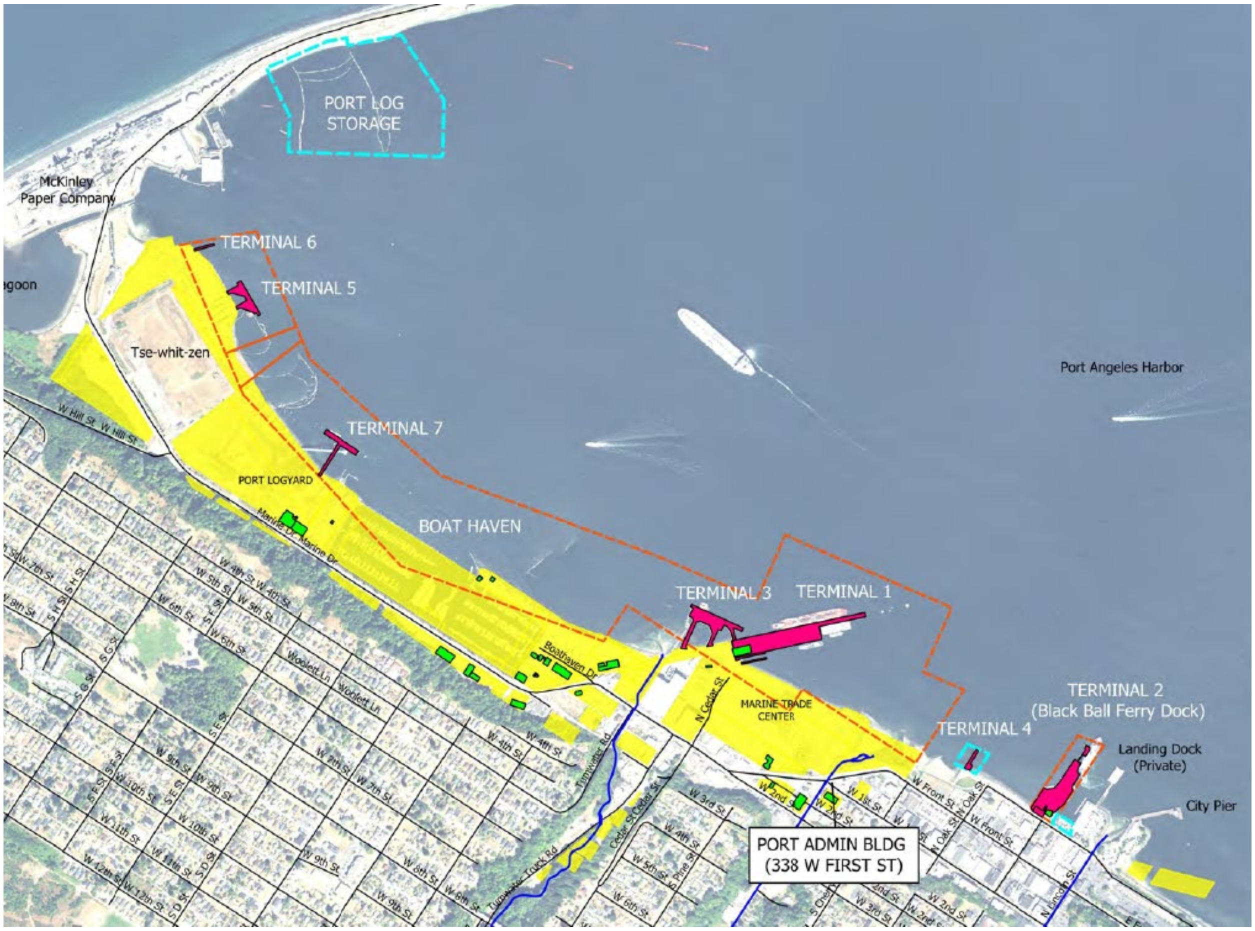


Figure 14. Map of the Port of Port Angeles terminal facilities and property. The red polygons represent terminal facilities, green polygons represent port-owned buildings, and the yellow area represents port property. The red dotted lines outline Port Management Agreement Areas, and the blue dotted lines represent Port Aquatic Lease Areas. (Comprehensive Scheme of Harbor Improvements, 2025)

Of significance is terminal 2, just west of the City Pier, which is leased to the Coho Black Ball Ferry Line. The Black Ball Ferry is a major international transportation hub between Port Angeles and Victoria, British Columbia, carrying more than 26 million passengers and 7 million vehicles since its establishment in 1959, with nearly 500,000 paying passengers transported in 2018 alone. Moving west, terminal 4 is leased to Arrow Launch Services, a private company that provides year-round launch and freight services. Terminals 1 and 3 are operated by the port as part of their marine trades work, offering loading and off-loading of general cargo. West of terminal 3 lies the Port Angeles Boat Haven, capable of mooring 410 private and working vessels with slips to support 50 foot vessels and 200 foot broadside. The center float features a set of enclosed boat houses. Further west along the Port Angeles waterfront lies Terminal 7, which supports larger vessels, including an oil response vessel owned by the National Response Corporation, a couple of larger, privately-owned vessels. At the westernmost point of Port Angeles Harbor, terminals 5 and 6 are not currently in operational use. However, the area just south of Sail and Paddle Park is designated for port log storage. Two other facilities of note lay at the base of the Ediz Hook: the McKinley Paper Plant and the Marathon Fuel Tank Farm. The paper plant is currently not in operation and is being tended to by a small crew of staff while the plant is on the market.

In Sequim Bay, approximately 18 miles east of Port Angeles, the John Wayne Marina sits on the western edge of the bay. As avid maritime enthusiasts and frequenters of Washington's coastal waters, the John Wayne family donated this land to the Port of Port Angeles with the condition that they would use the land to build a marina. With more than 300 slips available for private moorage, the John Wayne Marina is a gateway for the public to access the waters of the Strait of Juan de Fuca.

To help support and expand the day-to-day operations of the marine trades, the port assumed ownership of William R. Fairchild International Airport back in 1951. The airport is located on the west side of Port Angeles on a 797-acre property well above the tsunami inundation zone. With two runways in operational use, the airport also supports other commercial and non-profit organizations including Angeles Communication, Budget Rent a Car, FedEx, and the Life Flight Network. Notably, the airport is also home to Clallam County's Disaster Air Relief Team's (DART) Operations Center, which provides transport of emergency goods and services once activated for emergency response by Clallam County Emergency Management. The port also owns the La Push Marina and the Sekiu Airport in western Clallam County, which was not included in the scope of this strategy.

Outside of the terminal facilities, the Port Angeles waterfront area remains a significant commercial hub for the surrounding community for residents and visitors alike. Major community events, such as the Dungeness Crab Festival, are held in waterfront buildings such as the Field Arts and Events Hall or the Port Angeles Wharf. Additionally, many restaurants and stores scatter the blocks of Front and 1st Streets, with residential areas largely uphill.

Background of Earthquake and Tsunami Risk to Port Angeles and Sequim Bay

As a major maritime community along the Strait of Juan de Fuca with a highly developed waterfront within the inundation zone, residents, businesses, visitors and the maritime community are vulnerable to infrequent but potentially catastrophic geological threats, including major tsunamigenic earthquakes. The greatest risk comes from the Cascadia Subduction Zone, in which earthquakes can exceed a magnitude of 9.0 and bring severe to violent shaking (MMI 8 – 9, see Figure 15) to the area. Shaking of this intensity could cause slight to significant damage to specially designed structures. Well-constructed framed buildings might be thrown out of alignment or shifted off their foundations. Poorly built structures could experience severe damage or partial collapse, including the fall of chimneys, factory stacks, columns, walls, and other heavy structural components.

A magnitude 9 earthquake would also generate a tsunami that could impact the entire U.S. West Coast. It takes just 20 minutes for tsunami waves to arrive at the entrance of the Strait of Juan de Fuca. These waves would arrive in Port Angeles and Sequim Bay about 60 and 90 minutes after the earthquake rupture, respectively. Detailed tsunami wave arrival timings are discussed later in this section. An event of this size may well result in the worst natural disaster that the United States has ever seen.

Due to its geography, earthquake shaking from other nearby crustal faults (such as the Sadie Creek fault, Utsalady fault, and South Whidbey Island fault) will likely be felt in the Port Angeles and Sequim Bay areas, although the intensity and amount of shaking will be drastically reduced when compared to a local Cascadia Subduction Zone earthquake. Researchers are still working to understand more about the frequency and tsunamigenic potential of these nearby fault zones.

While the built environment has changed dramatically over the past 100 years, the impacts of previous tsunamis on the coastlines of Port Angeles is historically embedded in its geologic record at Salt Creek to the west and Discovery Bay to the east (Hutchinson, Peterson, & Sterling, 2013, and Garrison-Laney & Miller, 2017). Port Angeles has experienced tsunamis in the past and will inevitably experience them again. It is not a question of if, but when, the next tsunami will occur.

Intensity	Shaking	Description/Damage
I	Not felt	Not felt except by a very few under especially favorable conditions.
II	Weak	Felt only by a few persons at rest,especially on upper floors of buildings.
III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

Figure 15. Abbreviated descriptions of the impacts of earthquake shaking in the Modified Mercalli Intensity (MMI) scale. USGS ShakeMaps suggest the Port Angeles and Sequim Bay areas could experience IX - X (violent to extreme) shaking intensities in a Mw 9.0-9.3 Cascadia Subduction Zone scenario.

This maritime-focused study presents tsunami modeling results from one distant and one local tsunamigenic sources for this region. Scenario one represents a tsunami generated by a distant magnitude 9.2 Alaska Aleutian Subduction Zone (AASZ) similar to the 1964 Good Friday Alaska Earthquake but with a modified epicenter to direct more tsunami energy to Washington's coastline for conservative results. Scenario two represents a local magnitude 9.0 full-margin earthquake of the Cascadia Subduction Zone (CSZ). These two modeled earthquake scenarios represent Washington's current "maximum considered" tsunami hazard from distant earthquakes in the Pacific Ocean and local earthquakes on the CSZ. The tsunami generation from these AASZ and CSZ scenarios were also assessed regionally for all of Puget Sound by the Washington Geological Survey in 2021 (CSZ) with an upcoming AASZ publication expected in early 2026. These scenarios have been adopted for preparedness, mitigation, response, and recovery planning statewide. Refer to both Dolcimascolo and others (2022) and this study's associated Technical Report for a greater geologic background and temporal history of the CSZ earthquake source, in addition to specific details of the earthquake scenarios used for the modeling of this maritime strategy.

In the following subheadings, we outline the study area of this tsunami hazard assessment and present site-specific results from each modeled earthquake scenario. These results cover 1) onshore inundation depths, 2) tsunami current speeds, and 3) minimum offshore water depths. We also include information gathered from synthetic tide gauge data recorded over simulated time to provide insights into when tsunami waves arrive, the timing of the largest wave crests and troughs, and how long impacts may persist.

Study Area and Data Outline

The study area for this maritime assessment breaks into four boundary regions: three within the Port Angeles Harbor (Tip of the Hook, Base of the Hook, and Waterfront) and one to capture the John Wayne Marina within Sequim Bay (Figures 16 and 17). We present estimated tsunami impacts such as maximum onshore inundation depths, maximum current speeds, and minimum offshore water depths at both the Mean High Water (MHW) and Mean Low Water (MLW) tide-stages. All tsunami models were generated on 1/9th arc-second elevation grids and simulated for 14 and 10 hours for the AASZ and CSZ scenarios, respectively. This site-specific modeling, which considers factors such as bare-Earth topography, bathymetry, and coastal dynamics, is vital to the assessment of potential tsunami impacts on critical maritime infrastructures. Through comprehensive analysis and simulation, the study aims to inform the development of effective mitigation measures, emergency response plans, and long-term strategies to safeguard the Port of Port Angeles and its maritime community against the threat of tsunamis.

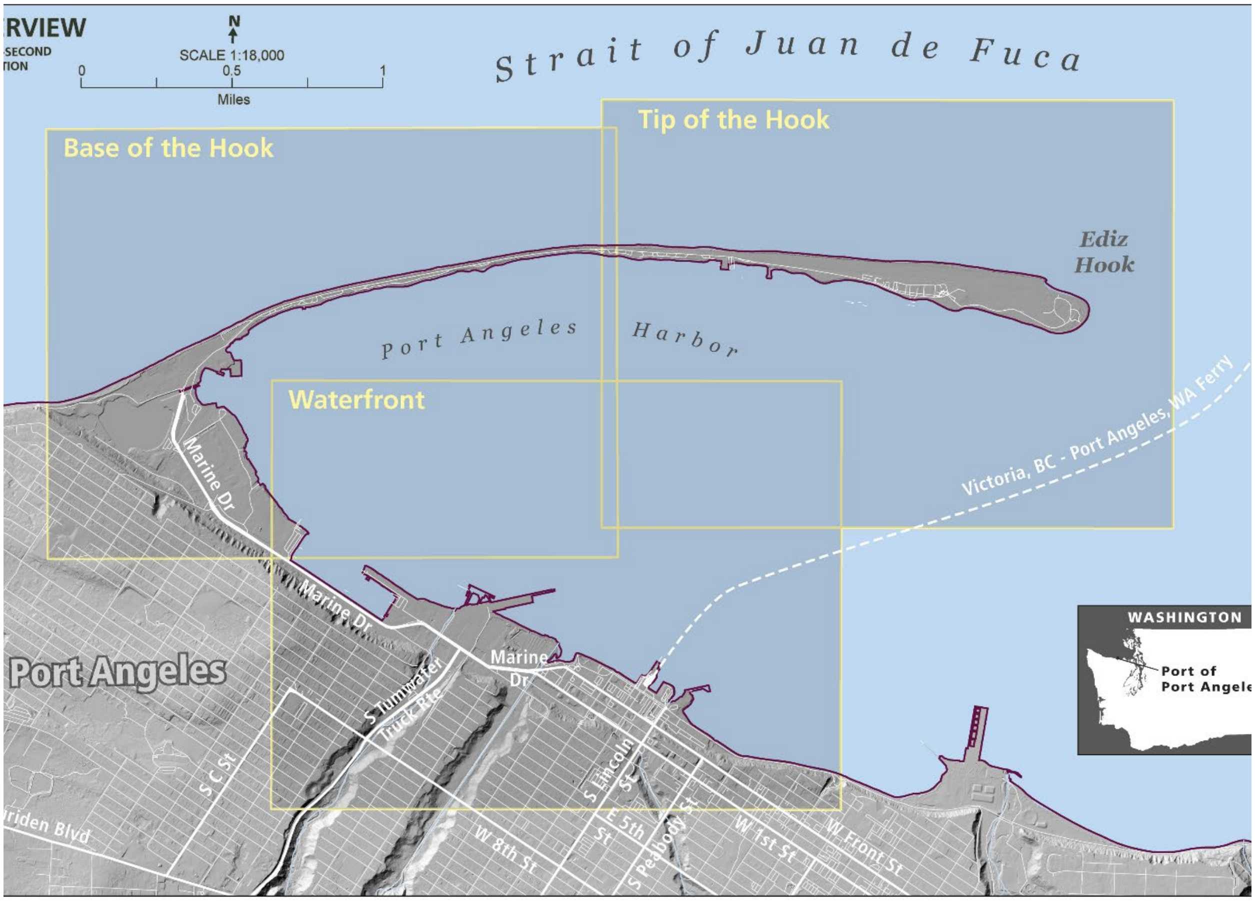


Figure 16. The Port Angeles Harbor study area for the Port Angeles and John Wayne Marina Tsunami Maritime Response and Mitigation Strategy. The area was broken into three sections for improved readability for the model results: Tip of the Hook, Base of the Hook, and the Waterfront.

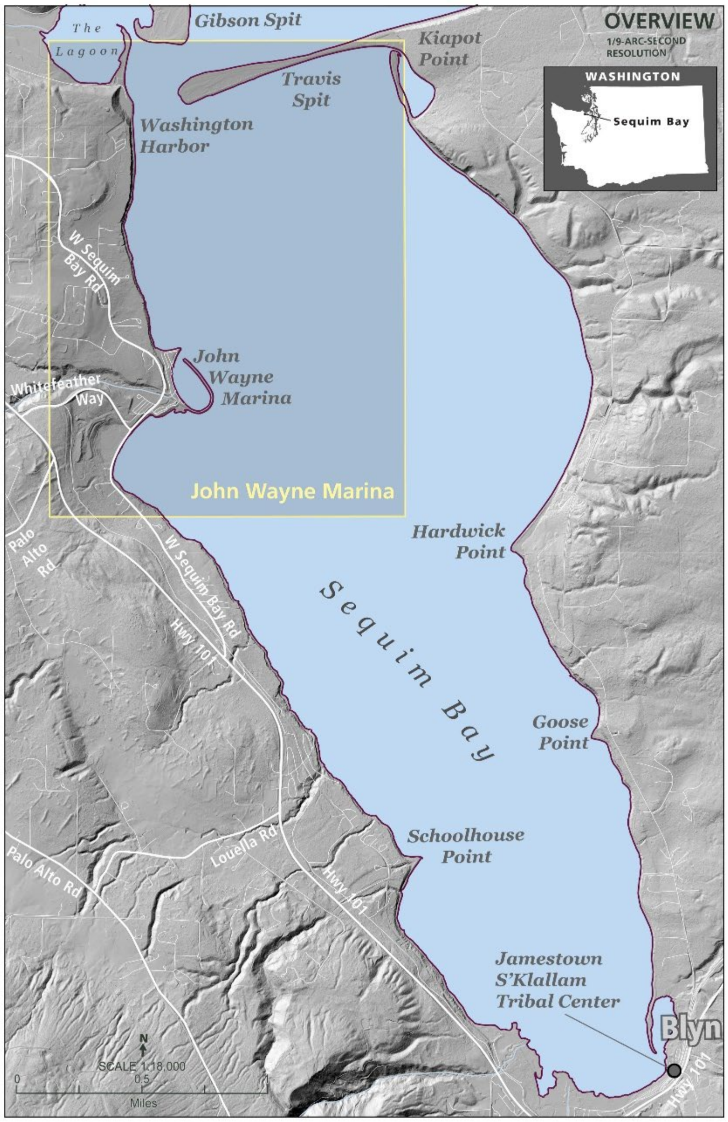


Figure 17. Study area for the portion of Sequim Bay included within the strategy, which captures the John Wayne Marina

Maximum Onshore Tsunami Inundation

Potential tsunami inundation (tsunami-induced flooding over previously dry land) poses significant risk to much of the built-up infrastructure in Port Angeles and Sequim Bay. The following figures provide information on both modeled tsunami inundation extent (how far inland) and the depth of flooding from each simulated tsunami scenario if the tsunami arrived at Mean High Water.

Alaska Aleutian Subduction Zone

When simulating the AASZ earthquake scenario, the ensuing modeled tsunami shows limited inundation throughout the Port Angeles Harbor and Sequim Bay areas. At the Tip of the Hook (Figure 19) some USCG property such as the helicopter landing pad and two minor structures are inundated with a couple feet of water. As you shift west towards the mainland, the eastern slope of the Ediz Hook beaches are inundated which may temporarily cover Ediz Hook Road in about 1 foot of water. At the Base of the Hook (Figure 20), the lagoon will overfill and inundate surrounding areas with a few feet of water. The far west side of port property near terminal 6 will be inundated with a couple feet of water as well. In the Waterfront (Figure 21) area, there is minimal inundation at Hollywood Beach just south of the City Pier. In Sequim Bay (Figure 22), the Travis Spit gets inundated and completely overtopped with about 6 feet of water. Outside of the spit, the steeper slopes of the area limit inundation around the Pacific Northwest National Laboratory and John Wayne Marina. Generally, less than two feet of inundation is expected along the Port Angeles and Sequim Bay areas.

The Port Angeles Harbor has approximately 4 hours and 30 minutes from the start of the earthquake before waves arrive, and Sequim Bay will see waves start at about 5 hours after the start of the earthquake. In the Port Angeles Boat Haven and John Wayne Marina, offshore wave heights will approach 5- and 3-foot maximums throughout the tsunami (Figures XX and XX, respectively).

Of note in the Port Angeles Harbor areas, the sixth and seventh wave heights match, if not exceed, the water level changes of the first and second waves in this distant AASZ earthquake scenario tsunami model. This aligns to real world observations seen in the July 29th, 2025 M8.8 Kamchatka earthquake-generated tsunami, in which the sixth wave was the maximum recorded wave height at the Port Angeles Tide Gauge (Figure 18).

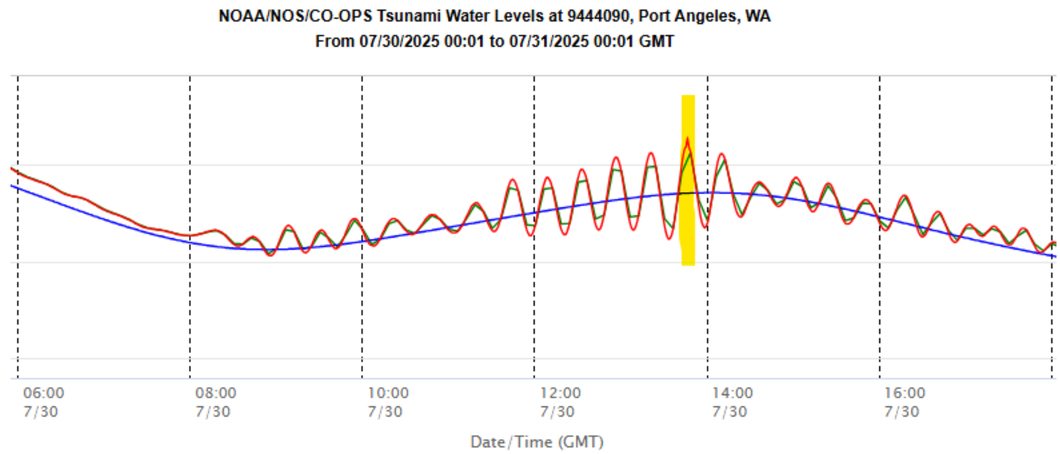


Figure 18. Tide gauge observations on for the distant tsunami generated from the M8.8 earthquake off the coast of Kamchatka, Russia. All times shown above are in GMT and data is reflected at Mean Lower Low Water (MLLW). The blue line represents predicted tide levels while red represents the observed tide throughout the tsunami. The highlighted wave crest was the highest recorded at Port Angeles and was reflected in the sixth wave at a height of approximately 1.4 feet. (NOAA, 2025)

This implies that the timing of the tidal cycle should be compared to the arrival time of the first and sixth wave to determine when the maximum severity inundation would be expected.

While boaters may be inclined to take their vessels out to deeper water, the best protective actions to take are to ensure that your boat is securely tied at the marina and follow your evacuation route to high ground. Tsunami waves differ from traditional wind waves and even wave heights a couple of feet higher than normal can cause damage to dock infrastructure and vessels. Given the amount of time before tsunami waves arrive, messaging should emphasize staying on high ground to prioritize life safety.

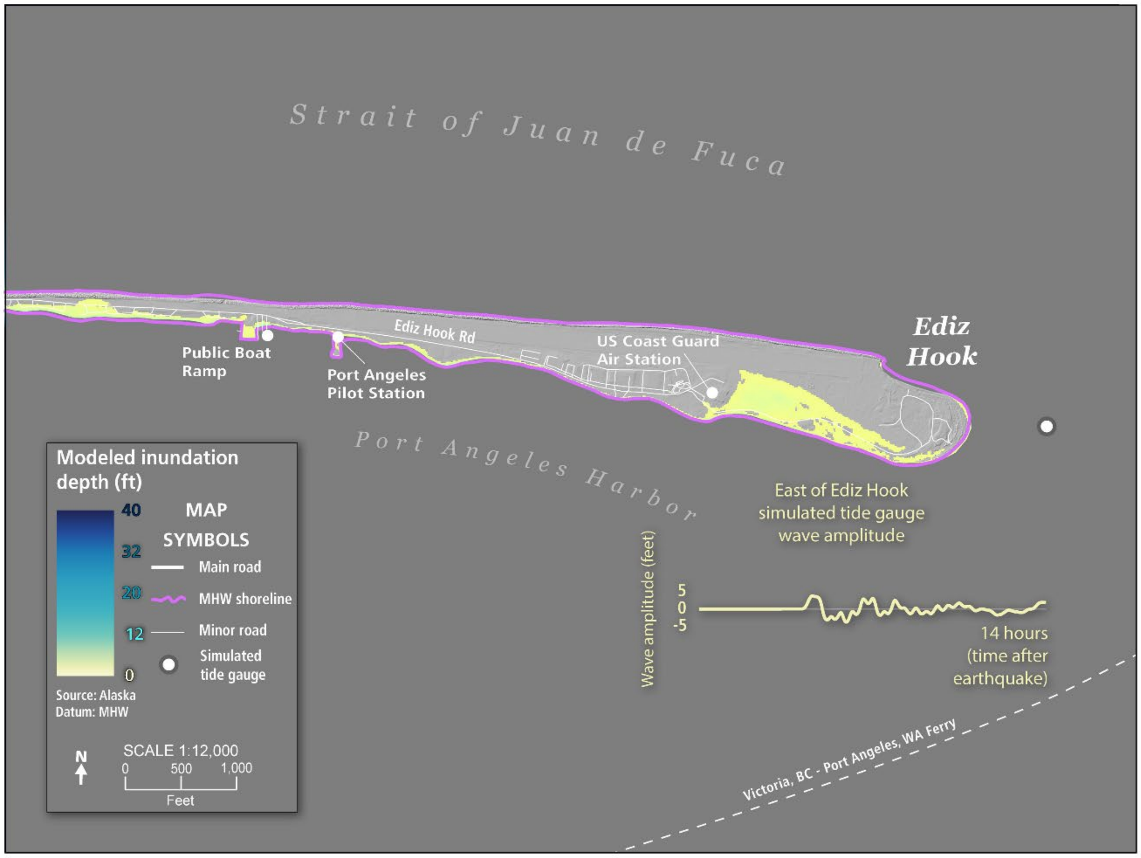


Figure 19. Modeled maximum tsunami inundation depths over land on the tip of the Ediz Hook in the Alaska Aleutian Subduction Zone scenario. Lighter yellow and very light green shades represent inundation depths between 0 – 2 feet, respectively. Tidal datum: Mean High Water. Model resolution: 1/9th arc-second (~3 meters).

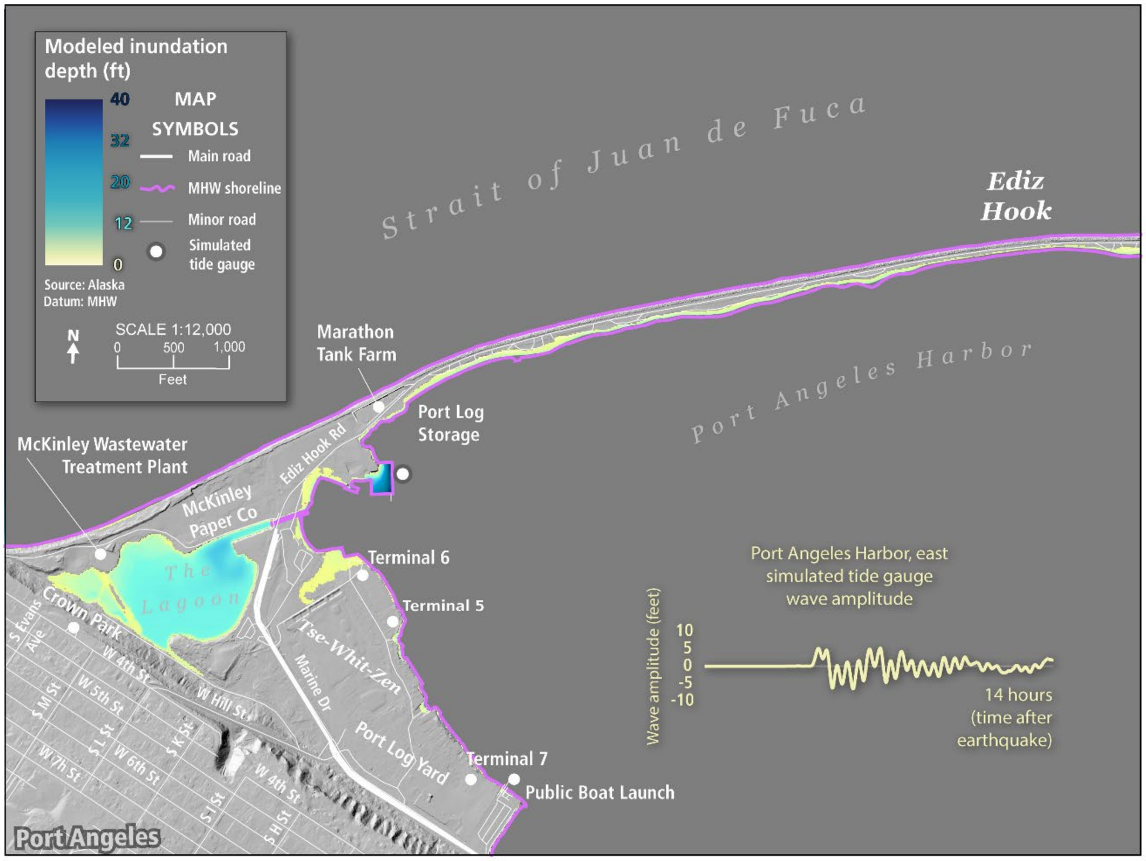


Figure 20. Modeled maximum tsunami inundation depths over land at the base of the Ediz Hook in the Alaska Aleutian Subduction Zone scenario. Lighter yellow and aqua colors represent inundation depths between 0 – 12 feet, respectively. The darker the shade of blue, the more water is expected to inundate the area. Tidal datum: Mean High Water. Model resolution: 1/9th arc-second (~3 meters).

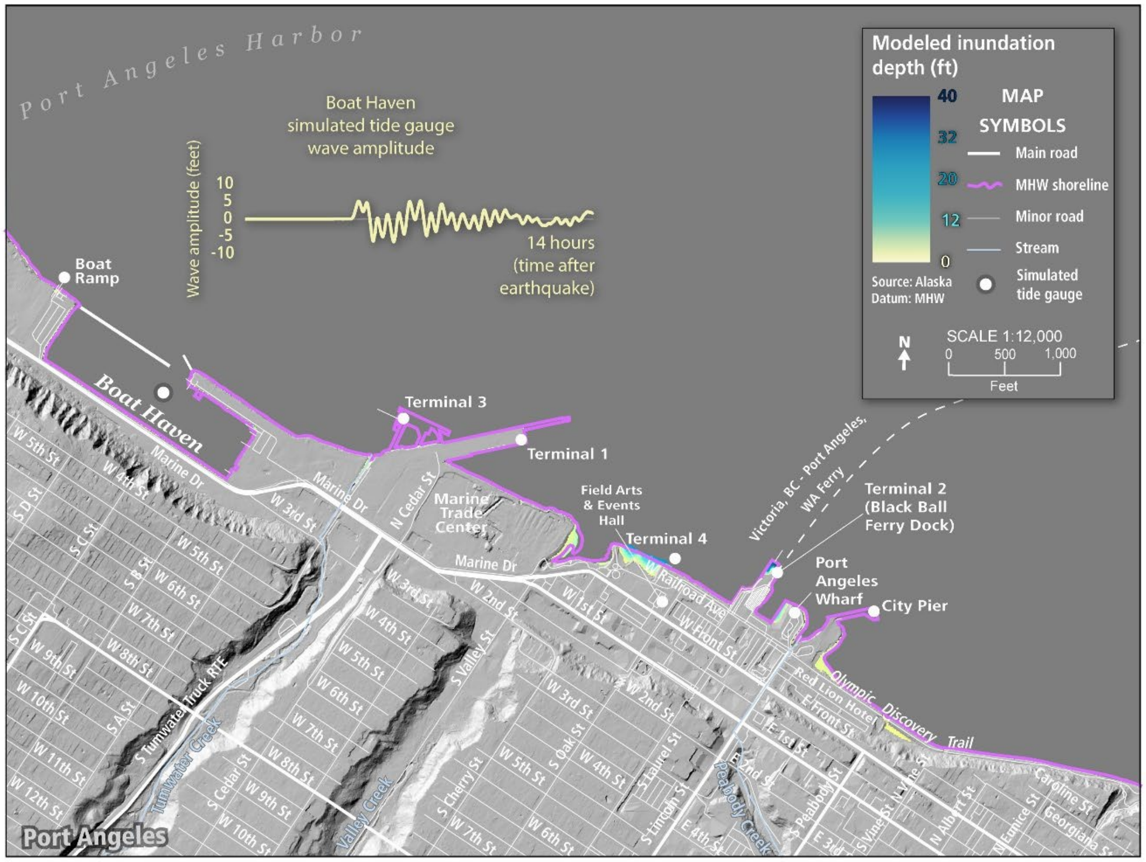


Figure 21. Modeled maximum tsunami inundation depths over land along the Port Angeles Waterfront in the Alaska Aleutian Subduction Zone scenario. Lighter yellow and aqua colors represent inundation depths between 0 – 12 feet, respectively. The darker the shade of blue, the more water is expected to inundate the area. Tidal datum: Mean High Water. Model resolution: 1/9th arc-second (~3 meters).

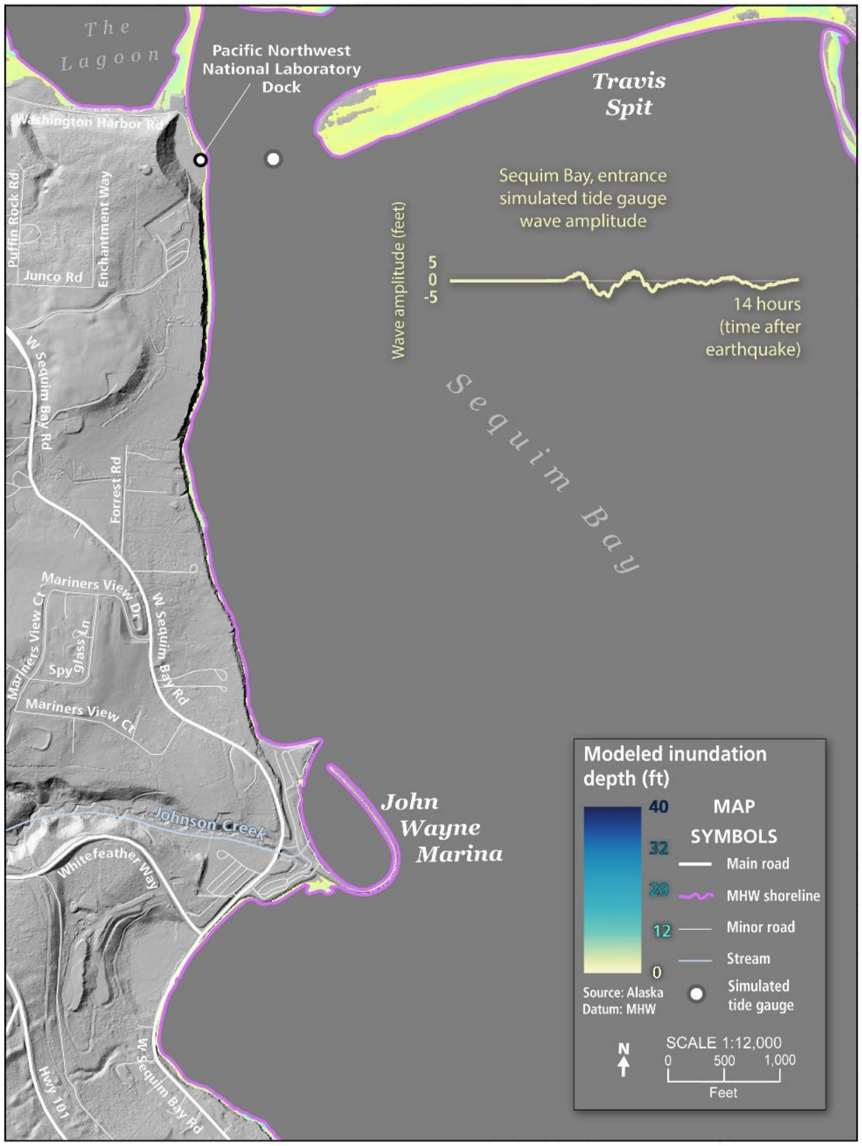


Figure 22. Modeled maximum tsunami inundation depths over land in the entrance to Sequim Bay for the Alaska Aleutian Subduction Zone scenario. Lighter yellow and aqua colors represent inundation depths between 0 – 12 feet, respectively. Tidal datum: Mean High Water. Model resolution: 1/9th arc-second (~3 meters).

Cascadia Subduction Zone (CSZ)

Inundation from the modeled Cascadia Subduction Zone (CSZ) earthquake scenario is expected to be devastating for the Port Angeles and Sequim Bay areas. On the tip of the Ediz Hook (Figure 23), the entirety of the Ediz Hook could be inundated with at least 13 feet of water. Moving to the base of the Hook (Figure 24), more than a dozen feet of water could overtop and inundate the lagoon all the way up until the base of the coastal uplands bluff, which acts as a natural barrier to inundation. Along the waterfront areas to the east (Figure 25), the model estimates the entire waterfront area to be inundated by at least 16 feet of water. While the bluff still limits the extent of inundation, the tsunami inundates up the Tumwater and Valley Creeks by nearly a quarter mile. Increasing elevation of the coastal uplands also limits inundation to the east, where East Front Street and East First Street will be inundated just past their intersections with Lincoln Street.

In Sequim Bay, the model shows the Travis Spit overtopped by tsunami waves. In this scenario, the steeper slopes are not enough to mitigate the impacts. The Pacific Northwest National Lab's dock and surrounding facilities could be inundated with several feet of water. Down south at the John Wayne Marina, the existing breakwater is overtopped by 2 – 3 feet of water, inundating the marina completely and up into the parking lot north of the marina (Figure 26).

To exacerbate the modeled risk to the areas, it's essential to note that water could start receding from the Port Angeles area within 25 minutes of the earthquake rupture. This is then followed by a leading wave crest that inundates the entire Port Angeles Harbor right around an hour after the start of the earthquake (Table 2). This is a very similar situation for Sequim Bay, in which water starts withdrawing from the entrance to the bay around 40 minutes after the start of the earthquake before a leading wave inundates and overtops the spit and enters the bay approximately one hour and 20 minutes from the onset of ground shaking.

Given the estimated impacts and limited response time from this event, everyone on land within the inundation zone should follow their evacuation route immediately after the 3 – 6 minutes of expected earthquake shaking stops. Once at safety, stay at high ground until your local officials say you can return to impacted areas. Boat owners at the docks or within the harbor area should ensure that their boat is tied up securely and head to high ground immediately on foot. Boat owners already out in the Strait of Juan de Fuca and unsure of their ability to make it back to the Boat Haven or John Wayne Marina within 20 or 40 minutes, respectively, should head out to the deeper waters of the Strait to a depth of 100 fathoms.

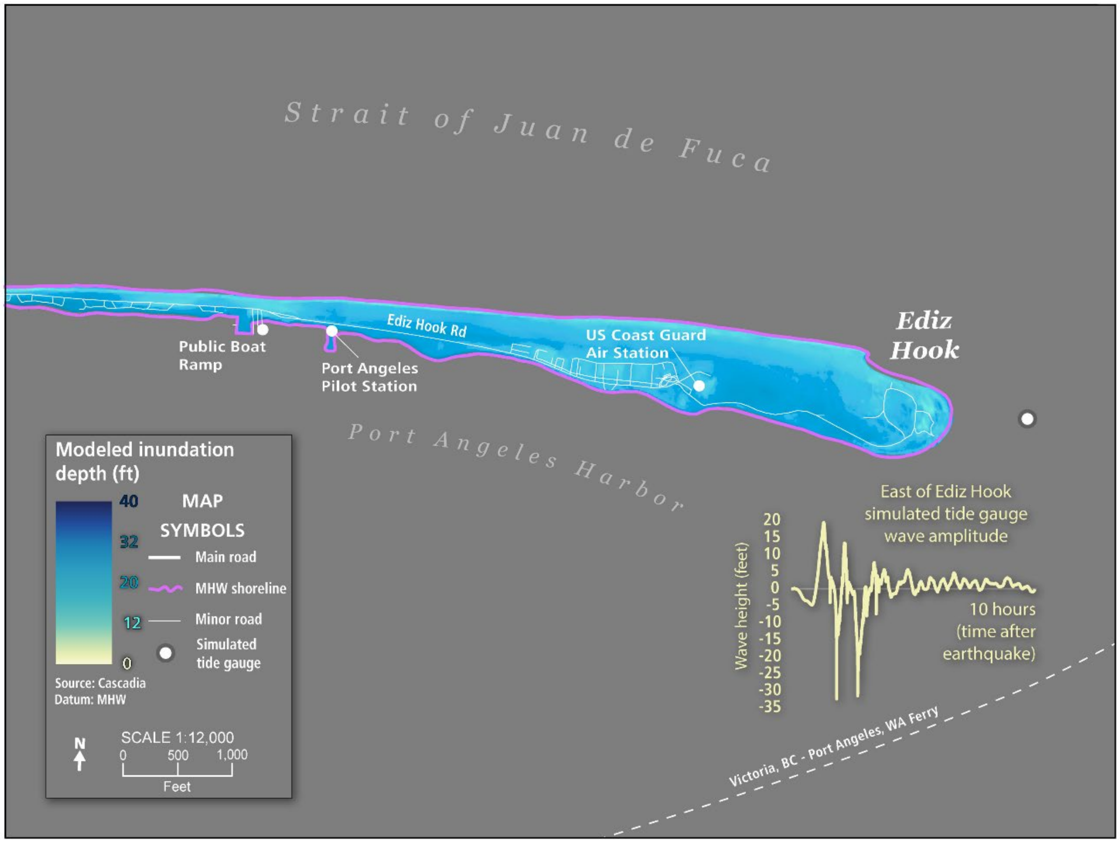


Figure 23. Modeled maximum tsunami inundation depths over land on the tip of the Ediz Hook in the Cascadia Subduction Zone scenario. Lighter yellow and aqua colors represent inundation depths between 0 – 12 feet, respectively. The darker the shade of blue, the more water is expected to inundate the area. Tidal datum: Mean High Water. Model resolution: 1/9th arc-second (~3 meters).

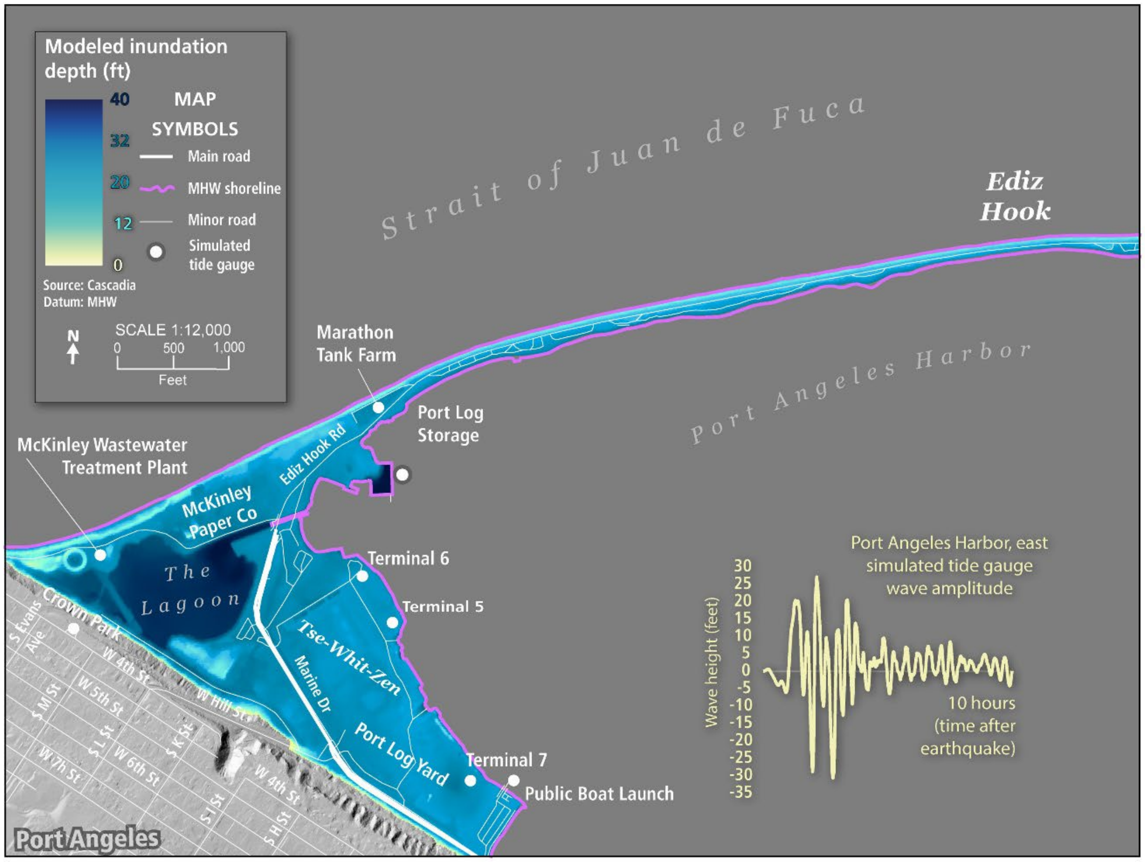


Figure 24. Modeled maximum tsunami inundation depths over land at the base of the Ediz Hook in the Cascadia Subduction Zone scenario. Lighter yellow and aqua colors represent inundation depths between 0 – 12 feet, respectively. The darker the shade of blue, the more water is expected to inundate the area. Tidal datum: Mean High Water. Model resolution: 1/9th arc-second (~3 meters).

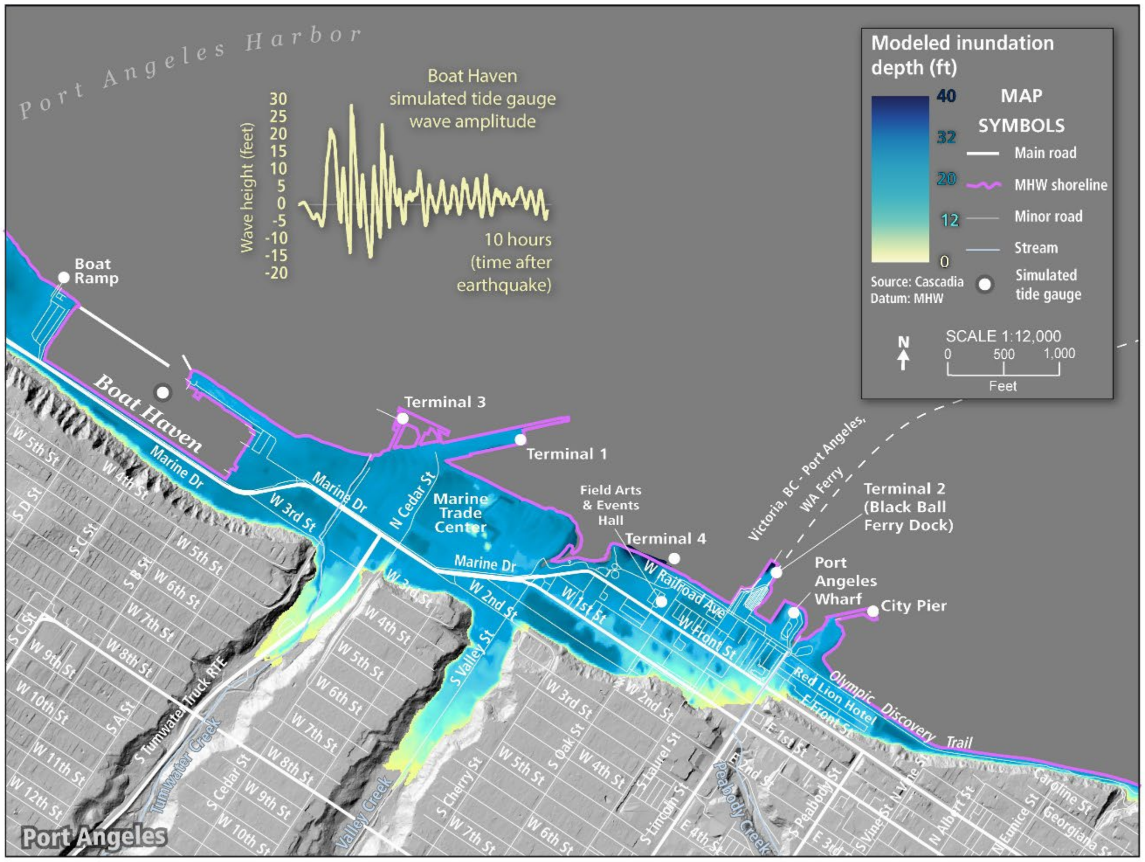


Figure 25. Modeled maximum tsunami inundation depths over land on the Port Angles Waterfront in the Cascadia Subduction Zone scenario. Lighter yellow and aqua colors represent inundation depths between 0 – 12 feet, respectively. The darker the shade of blue, the more water is expected to inundate the area. Tidal datum: Mean High Water. Model resolution: 1/9th arc-second (~3 meters).

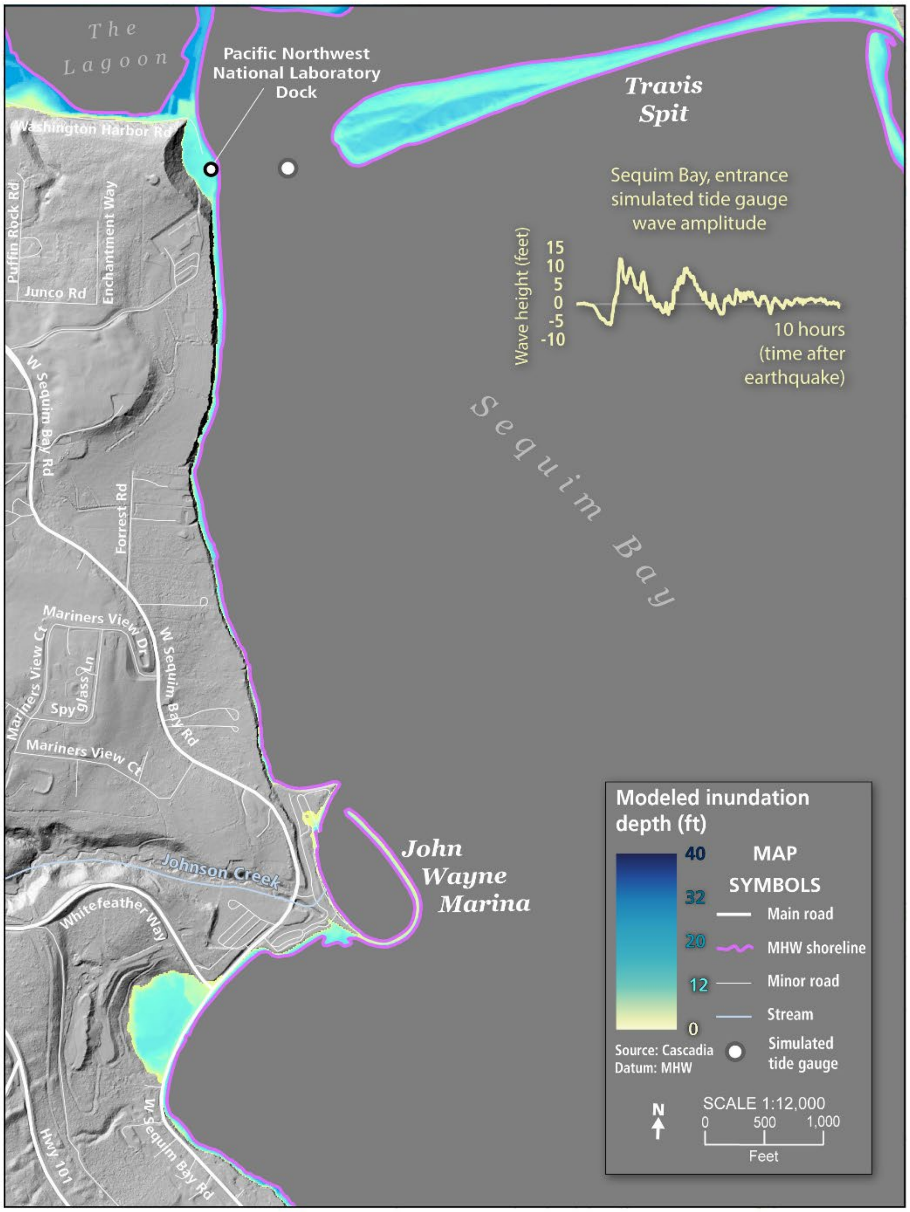


Figure 26. Modeled maximum tsunami inundation depths over land on tip of the Ediz Hook in the Cascadia Subduction Zone scenario. Lighter yellow and aqua colors represent inundation depths between 0 – 12 feet, respectively. The darker the shade of blue, the more water is expected to inundate the area. Tidal datum: Mean High Water. Model resolution: 1/9th arc-second (~3 meters).

Maximum Tsunami Current Speeds

An understanding of tsunami current speeds, when combined with inundation depths (momentum flux forces), can help approximate potential impacts to the existing built environment such as harbor infrastructure. The following information and figures summarize the maximum modeled tsunami current speeds in knots (a knot is equal to 1 nautical mile or ~1.15 land mi/hr) at any given time within the study area from each tsunami scenario. All modeled current speeds are the result of tsunami forces and do not represent pre-existing local current speeds. Normal day-to-day currents should be considered with the reported speeds when consulting these figures for a more accurate reflection of what total current speed in an area could be during a tsunami event.

For this strategy, current speeds were binned into four ranges: 0–3 knots, 3–6 knots, 6–9 knots, and >9 knots. These ranges generally follow the port damage categorization of Lynett and others (2014) that approximates hazards to ships and docking facilities. Speeds ranging from 0-3 knots represent no expected damage, 3-6 knots represent minor/moderate damage possible, 6-9 knots represent major damage possible, and speeds greater than 9 knots represent extreme damage possible. Note that these 3-6-9 knot expected damage thresholds tend to be accurate for newer (less than 30-40 years old) and well-maintained docks and harbor infrastructure. For older (greater than 40-50 years old) and less maintained docks, thresholds of 2-5-7 knots may be more appropriate to predict potential damage (Pat Lynett, University of Southern California, personal communication).

Any regions subject to high current speeds shown in the tsunami modeling may be much more widespread than what is shown. Due to this sensitivity, the recorded speeds on each figure represent the maximum values generated throughout the duration of the tsunami at either Mean High Water or Mean Low Water.

Certain topographic or engineered features, like entrances into harbors or marinas, may experience faster nearby currents than the surrounding areas. Additionally, small islands, land spits, or bathymetric features may also impact current speeds and form vortices. In general, narrower waterway channels and nearshore locations where normal currents and tide interactions are the greatest are also likely to have the most significant tsunami currents with the highest speeds.

Alaska Aleutian Subduction Zone (AASZ)

Modeled current speeds from the AASZ scenario exceed 9 knots at one location within the study area: the entrance in Sequim Bay and extending south beyond the entrance to the John Wayne Marina (Figure 30). These current speeds could cause moderate damage to the Pacific Northwest National Laboratory dock just West of the Travis Spit. At the John Wayne Marina, the marina is spared damage thanks to the topography of the land just north of the marina. This natural geographic feature will be referenced numerous times throughout this document thanks to the protection it provides to the marina. While the marina itself is shielded, the entrance to John Wayne Marina will see knots between 5 – 6 knots. Although there is no infrastructure at the entrance in areas with higher current speeds, the erosion and sedimentation of the breakwater will contribute to a higher risk of failure throughout this distant tsunami scenario. Additionally, the way that Sequim Bay is formed, with Travis Spit forming a narrow channel at the entrance, emphasizes the challenges that boaters face when trying to navigate tsunami waters. Eddies, whirlpools, and rapidly shifting current speeds highlight the importance of leaving your vessel tied up at the dock, or heading to the deepest water possible throughout the entire duration of a tsunami.

In the Port Angeles Harbor, current speeds from the tsunami may impact one significant area of concern: the Port Angeles Boat Haven entrance (Figure 29). With two breakwaters creating a channeling effect, current speeds approaching 9 knots are expected just outside of the entrance, traveling through the entrance and into the marina. These current speeds may cause moderate to major damage to dock infrastructure including the harbormaster dock and center floats. Current speeds then start slowing down as they split to each side of the boat haven, with 5 – 6 knot currents expected in the west side and 4 – 5 current expected to the east side. Although the current speeds reduce upon splitting, the west and east side may still see minor to moderate damage to the dock infrastructure itself. Based on the modeling, whirlpools and eddies may still form within the Boat Haven itself and just outside of the entrance, in addition to around the tip of Ediz Hook. Outside of the Port Angeles Boat Haven, current speeds are not expected to impact any other infrastructure outside of moving buoys located in the middle of the Harbor.

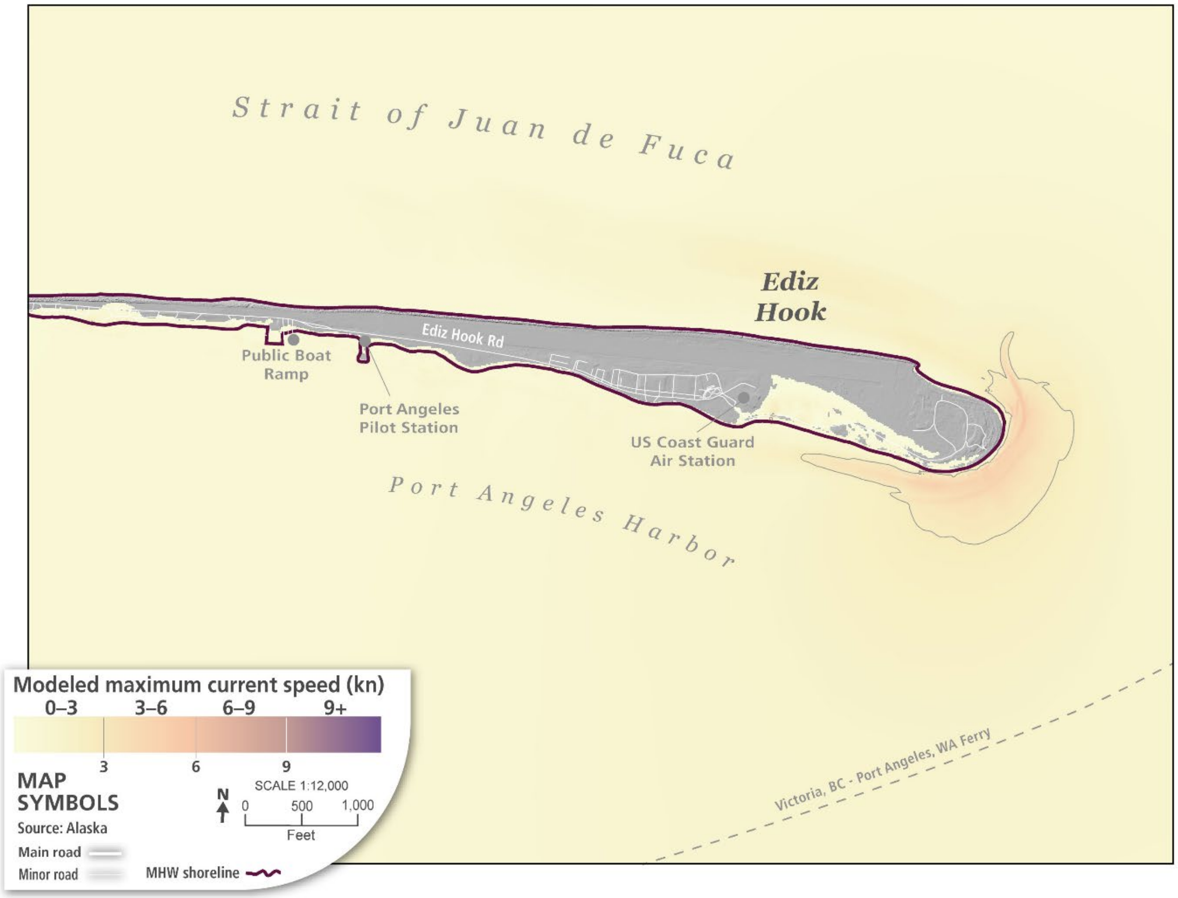


Figure 27. Modeled tsunami current speeds off the tip of Ediz Hook for the Alaska Aleutian Subduction Zone earthquake scenario. Tidal datum: maximum values generated between the Mean High Water and Mean Low Water runs. Model resolution: 1/9th arc-second (3 m).

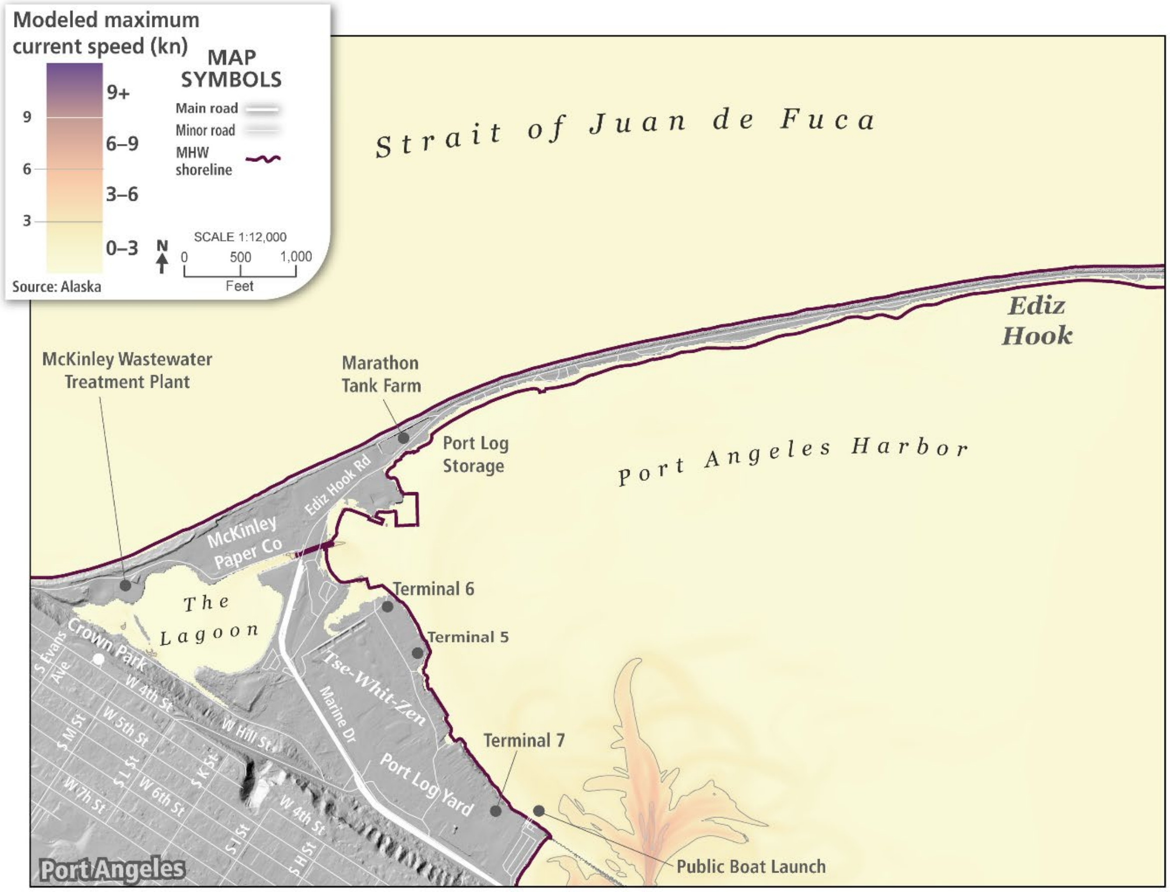


Figure 28. Modeled tsunami current speeds at the base of the Ediz Hook from the Alaska Aleutian Subduction Zone earthquake scenario. Tidal datum: maximum values generated between the Mean High Water and Mean Low Water runs. Model resolution: 1/9th arc-second (3 m).

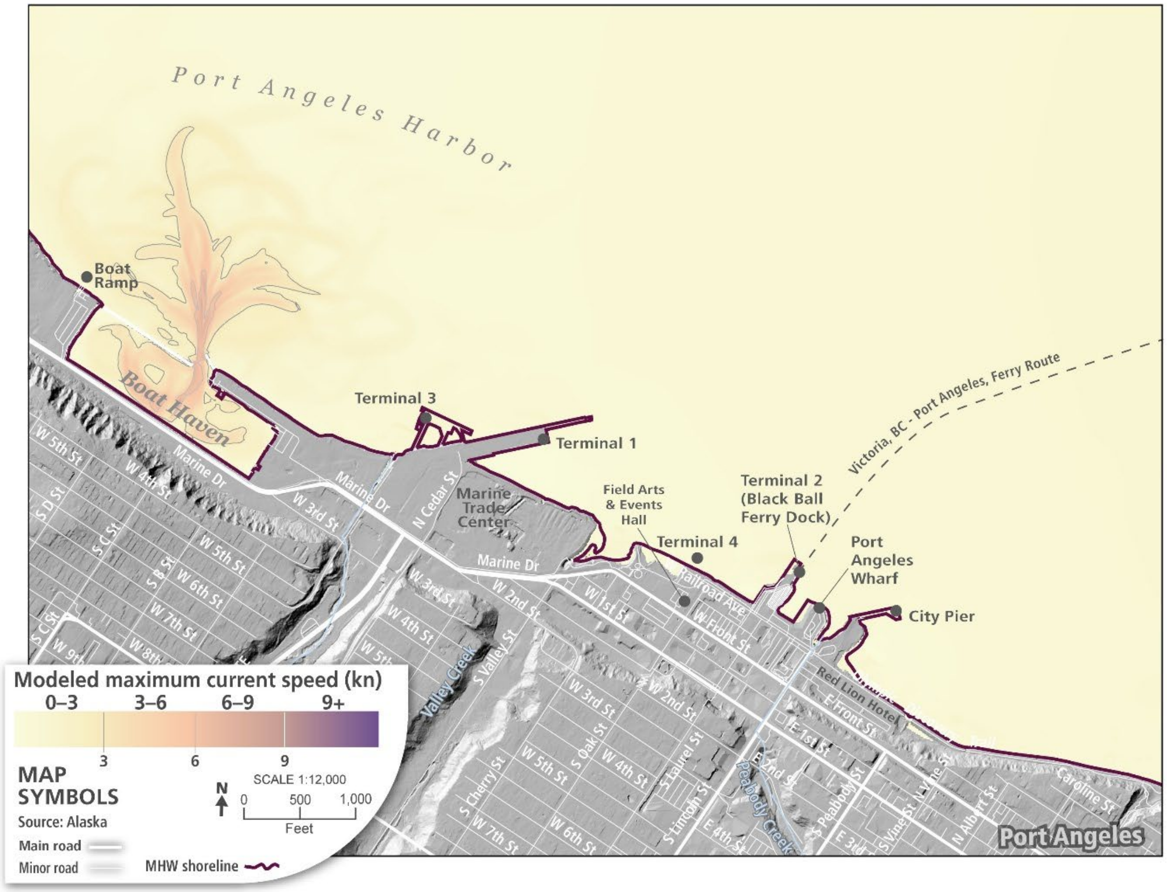


Figure 29. Modeled tsunami current speeds for the Port Angeles Waterfront from the Alaska Aleutian Subduction Zone earthquake scenario. Tidal datum: maximum values generated between the Mean High Water and Mean Low Water runs. Model resolution: 1/9th arc-second (3 m).

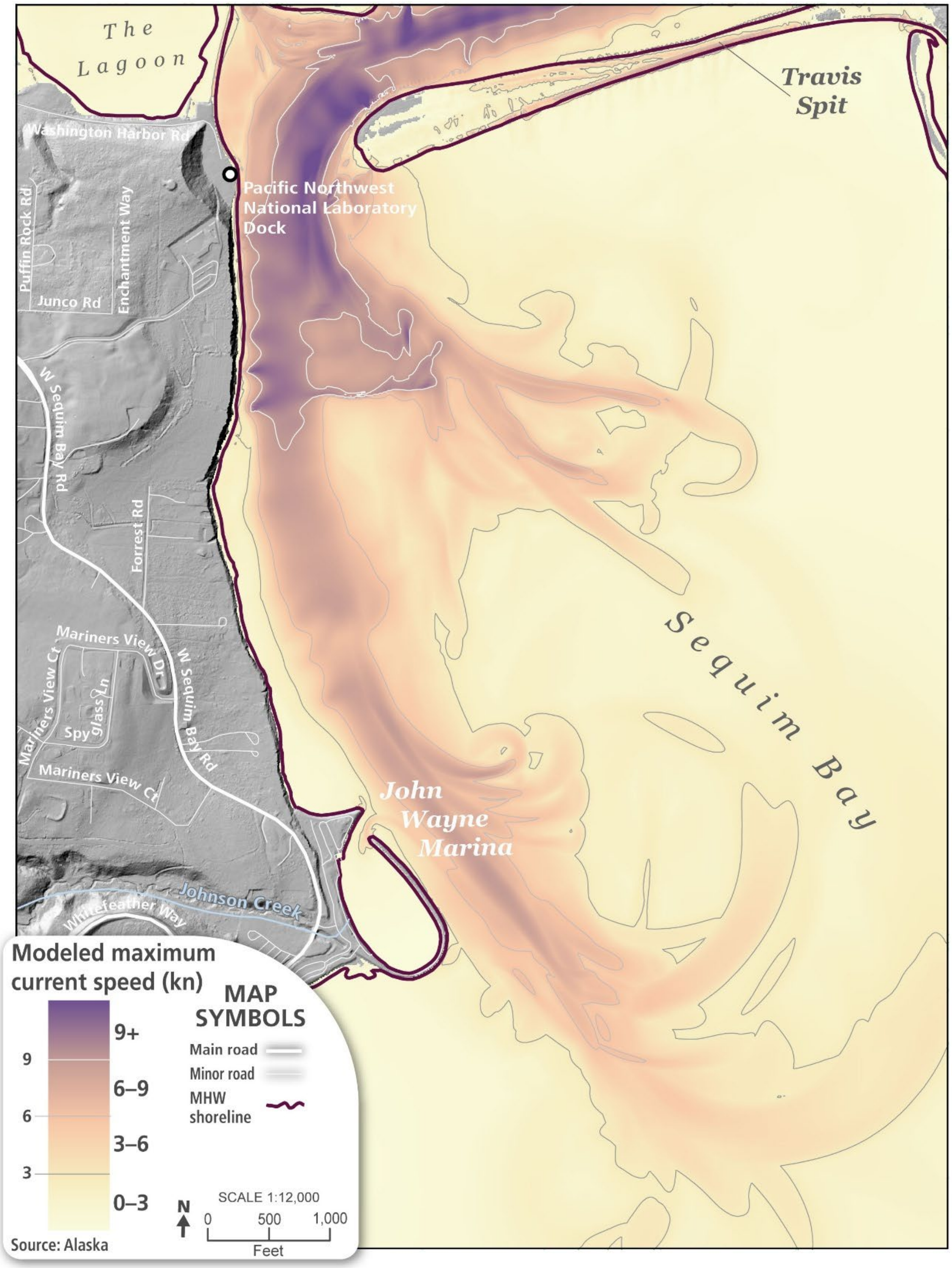


Figure 30. Modeled tsunami current speeds for the entrance to Sequim Bay including the John Wayne Marina from the Alaska Aleutian Subduction Zone earthquake scenario. Tidal datum: maximum values generated between the Mean High Water and Mean Low Water runs. Model resolution: 1/9th arc-second (3 m).

Cascadia Subduction Zone (CSZ)

The modeled Cascadia Subduction Zone scenario shows significant risk to infrastructure and boaters for both the Port Angeles Harbor and Sequim Bay areas. In the Port Angeles Harbor, the modeling shows approximately 15 knot current speeds just off the tip of the Ediz Hook, with current speeds ripping over the Ediz Hook after the wave wraps around the tip (Figure 31). The modeling shows large whirlpools generated right off the tip of the Hook and within the harbor which will last for hours. As the wave travels over the Ediz Hook, these rapid currents will contribute to catastrophic destruction of the USCG and Puget Sound Pilot Stations, creating significant amounts of debris and hazardous materials spills.

Moving to the base of the Ediz Hook (Figure 32), the widespread inundation will contribute to catastrophic impacts across the entire Port Angeles waterfront. At the Port Angeles Boat Haven (Figure 33), the model shows channeling of water between the breakwaters creates current speeds that potentially exceed 15 knots, far surpassing the threshold expected for catastrophic damage to the infrastructure and vessels throughout, with potentially complete destruction of both. The impacts to terminals 1 and 2, as the shoreline extends out underneath the constructed terminals. These topographical features can increase current speeds as the incoming waves wrap around the land. The 9 knot or faster current speeds may increase the impacts to the infrastructure. Given the widespread inundation and severe current speeds across the entire waterfront area of Port Angeles, there will likely be significant amounts of hazardous debris and sediment deposited across the area.

Regardless of location within Port Angeles Harbor, the described whirlpools and eddies will make it nearly impossible to navigate the shallow waters of the harbor.

In Sequim Bay (Figure 34), the channeling created by the naturally formed Travis Spit exacerbates the current speeds as it wraps around the spit and into the bay. Initially, water is rapidly drained out of the bay resulting in 15 knot currents before the initial inundating wave approaches. As the water then pushes back into the bay, the Pacific Northwest National Laboratory dock infrastructure is caught in currents greatly exceeding 9 knots, resulting in major damage if not complete destruction of their docks. For the John Wayne Marina, the outcropping of land north of the marina provides some protection from the worst impacts of the tsunami. However, the entrance and northern side of the marina will still see currents of ~6 – 8 knots based on the model, which may cause moderate to major damage to three small docks, including the fuel dock. These current speeds reduce deeper into the marina, although it should be noted that in this modeled scenario, the breakwater gets overtopped by a couple of feet of water, creating impacts to other docks in the marina. The majority of current speed impacts happen when the water levels are receding between waves, and with the incoming waves. Throughout the Sequim Bay area, including the areas north of the entrance, whirlpools and eddies will continuously create navigational challenges and additional hazards for boaters to navigate hours after the tsunami arrives. Debris and sediment will likely be spread throughout the area, and may deposit throughout the area, including geographic features like the Travis Spit.

Figure 31. Modeled tsunami current speeds around the tip of the Ediz Hook from the Cascadia Subduction Zone earthquake scenario. Tidal datum: maximum values generated between the Mean High Water and Mean Low Water runs. Model resolution: 1/9th arc-second (3 m).

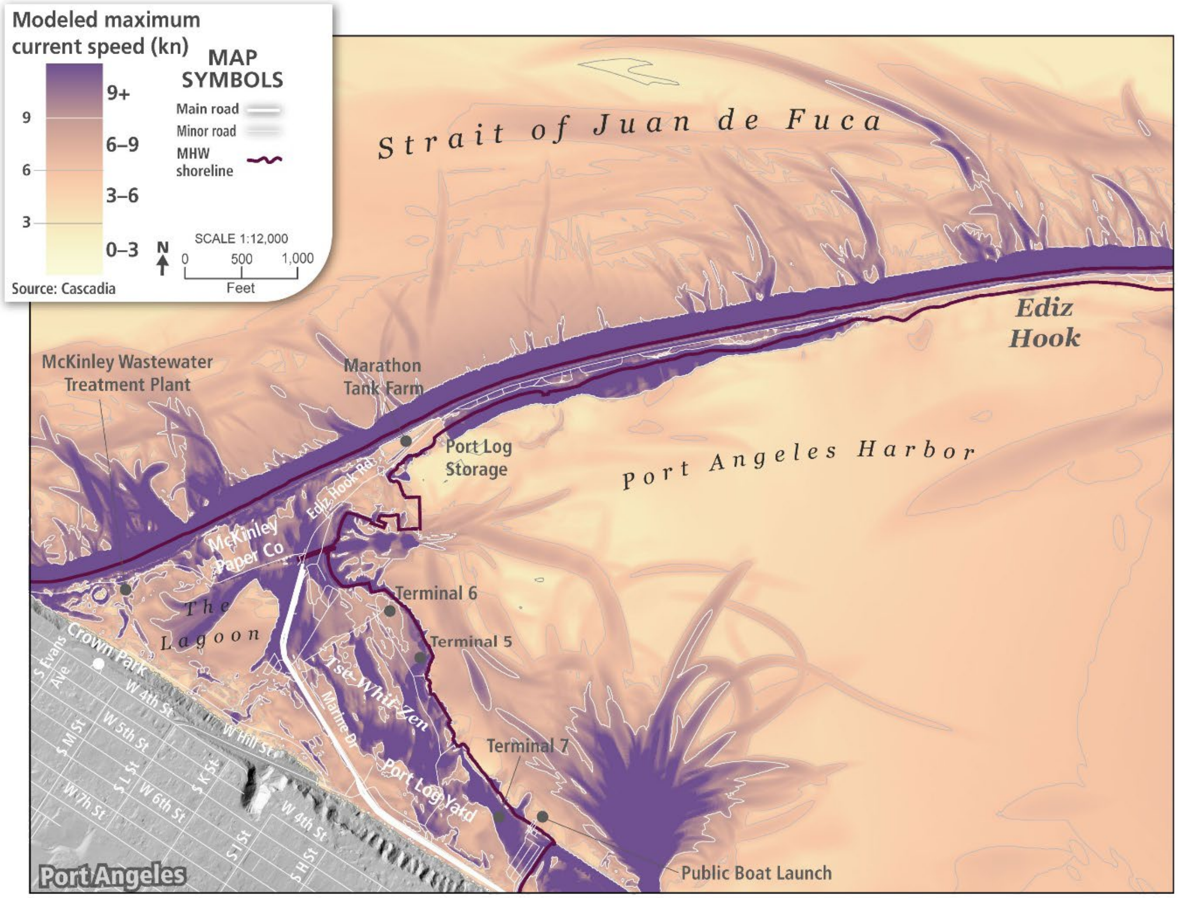


Figure 32. Modeled tsunami current speeds around the base of the Ediz Hook from the Cascadia Subduction Zone earthquake scenario. Tidal datum: maximum values generated between the Mean High Water and Mean Low Water runs. Model resolution: 1/9th arc-second (3 m).

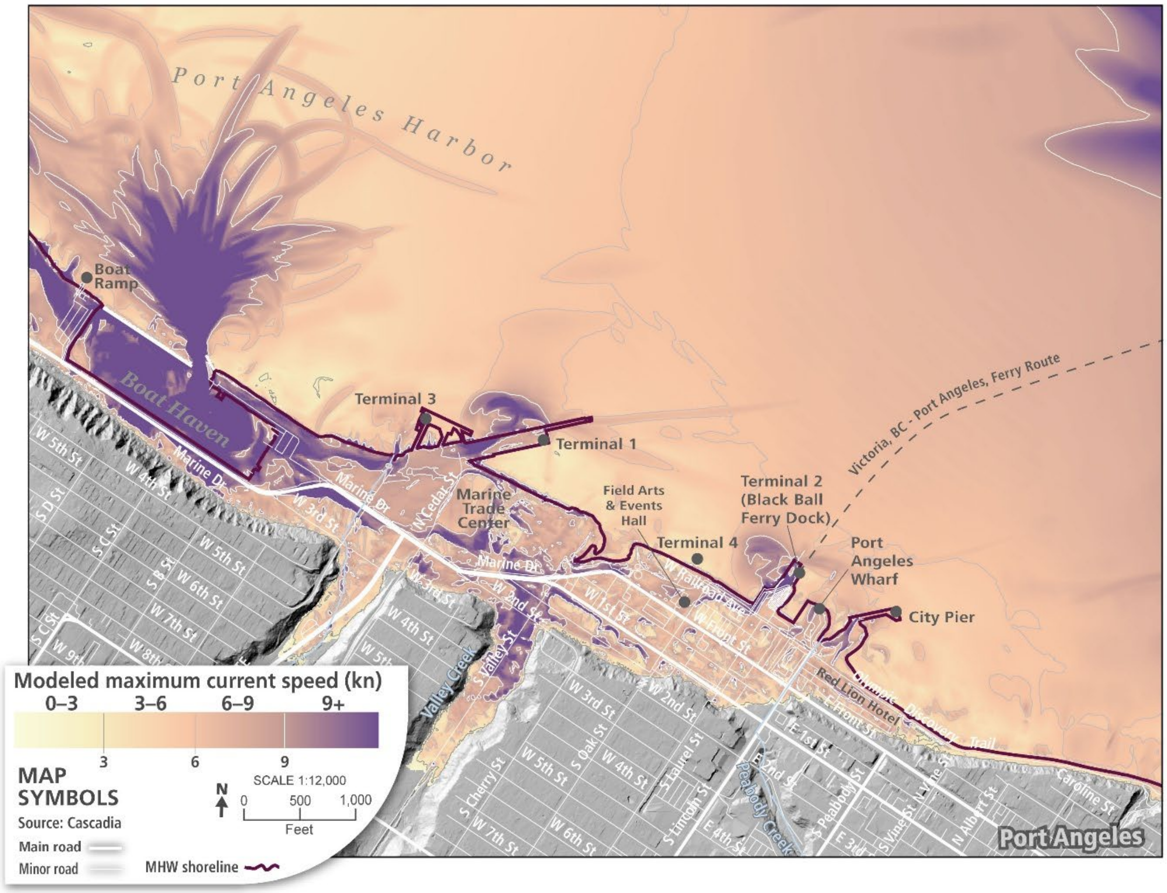


Figure 33. Modeled tsunami current speeds at the Port Angeles Waterfront from the Cascadia Subduction Zone earthquake scenario. Tidal datum: maximum values generated between the Mean High Water and Mean Low Water runs. Model resolution: 1/9th arc-second (3 m).

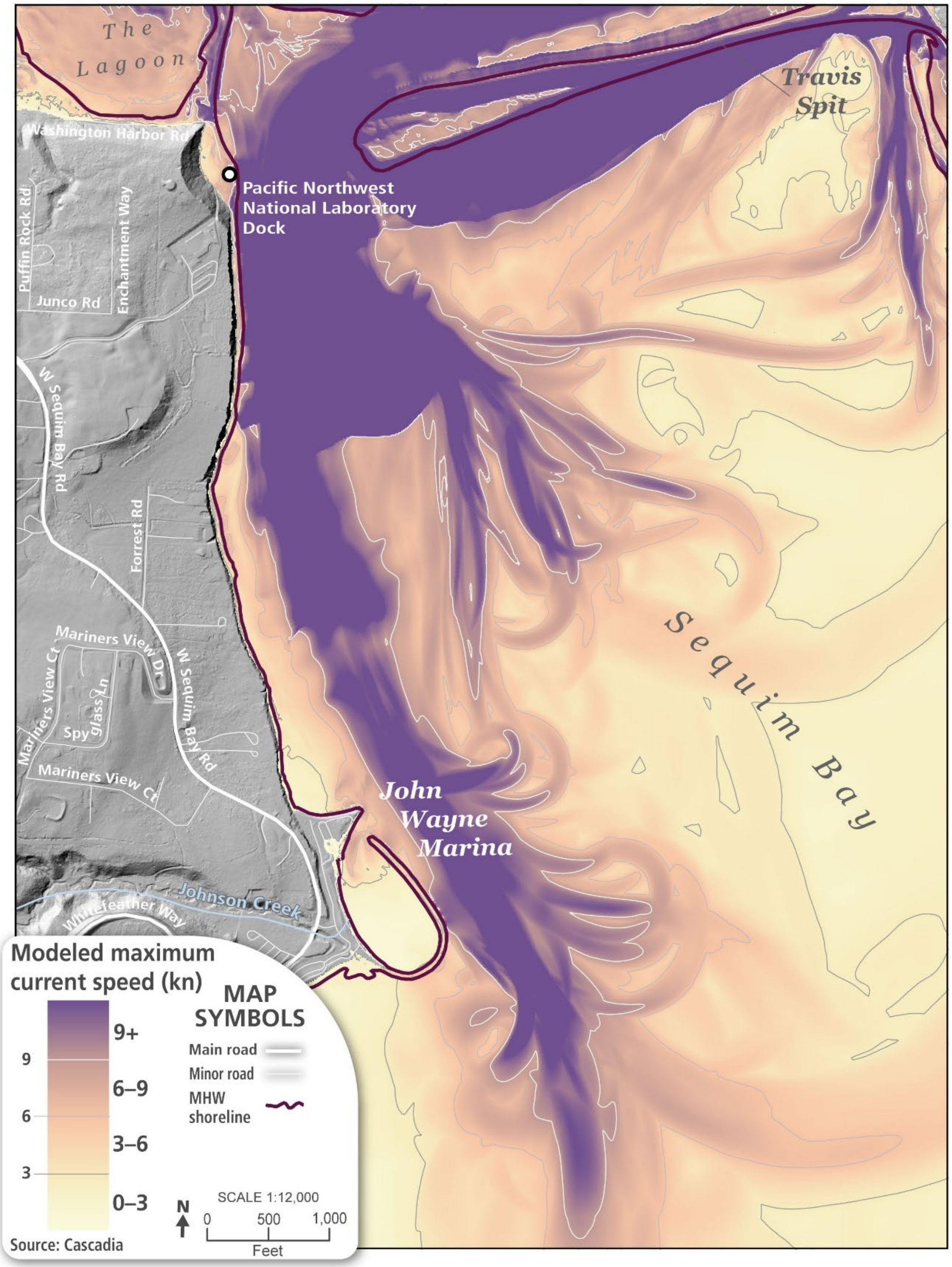


Figure 34. Modeled tsunami current speeds at the entrance to Sequim Bay and John Wayne Marina from the Cascadia Subduction Zone earthquake scenario. Tidal datum: maximum values generated between the Mean High Water and Mean Low Water runs. Model resolution: 1/9th arc-second (3 m).

Minimum Water Depth

The minimum water depths and derived drawdown, modeled for both the Alaska Aleutian Subduction Zone (AASZ) and Cascadia Subduction Zone (CSZ) tsunami scenarios highlight significant risks to boaters and vessels. As the water recedes during the trough of the tsunami, shallow areas could leave vessels grounded, making them immobile until the next rising wave. Any attempt to board vessels during this period would be dangerous, and boats trying to navigate away could be damaged if they encounter water that is too shallow. Boats may capsize with the next rising wave and be significantly damaged, if not destroyed. The drawdown process, which can expose large areas of the seafloor, also pose risks of rapid dragging and scour from sediment shifts, which could cause damage to both vessels and infrastructure.

These minimum water depths provide essential information for assessing where vessels with shorter drafts should avoid mooring and highlight areas that may need future dredging to reduce the risk of grounding. Figures 35, 36, 37 and 38 show drawdown for the distant AASZ scenario while Figures 39, 40, 41, and 42 illustrate the CSZ scenario. These maps are based on low tide conditions for a more conservative estimate.

Alaska Aleutian Subduction Zone (AASZ)

As shown in the modeling below, the primary areas of concern for vessels being grounded as a result of drawdown lie in the Port Angeles Boat Haven and John Wayne Marina areas (Figures 37 and 38, respectively). The Port Angeles Boat Haven water levels will drop to 0 – 3 feet of water depth in areas at the east, center, and west floats, leaving boats along the outside edges at risk of grounding. Particularly on the east side, the minimum water levels are expected to drawdown to approximately 3 – 6 feet or lower at points of every dock finger. In John Wayne Marina, the amount of drawdown is less severe. The eastern edge of the marina is expected to reach minimum depths of 3 – 6 feet, but the majority of the marina will maintain depths of 6 – 9 feet at a minimum.

Within Sequim Bay is a very small island located a few hundred feet south of the western tip of Travis Spit that may be a hazardous site for boaters out in the bay during a tsunami. As shown in Figure 38, water levels very close to the island reach depths of as little as 0 – 3 feet, with extended areas of 9 feet or less that could cause damage or ground unaware vessels in the area.

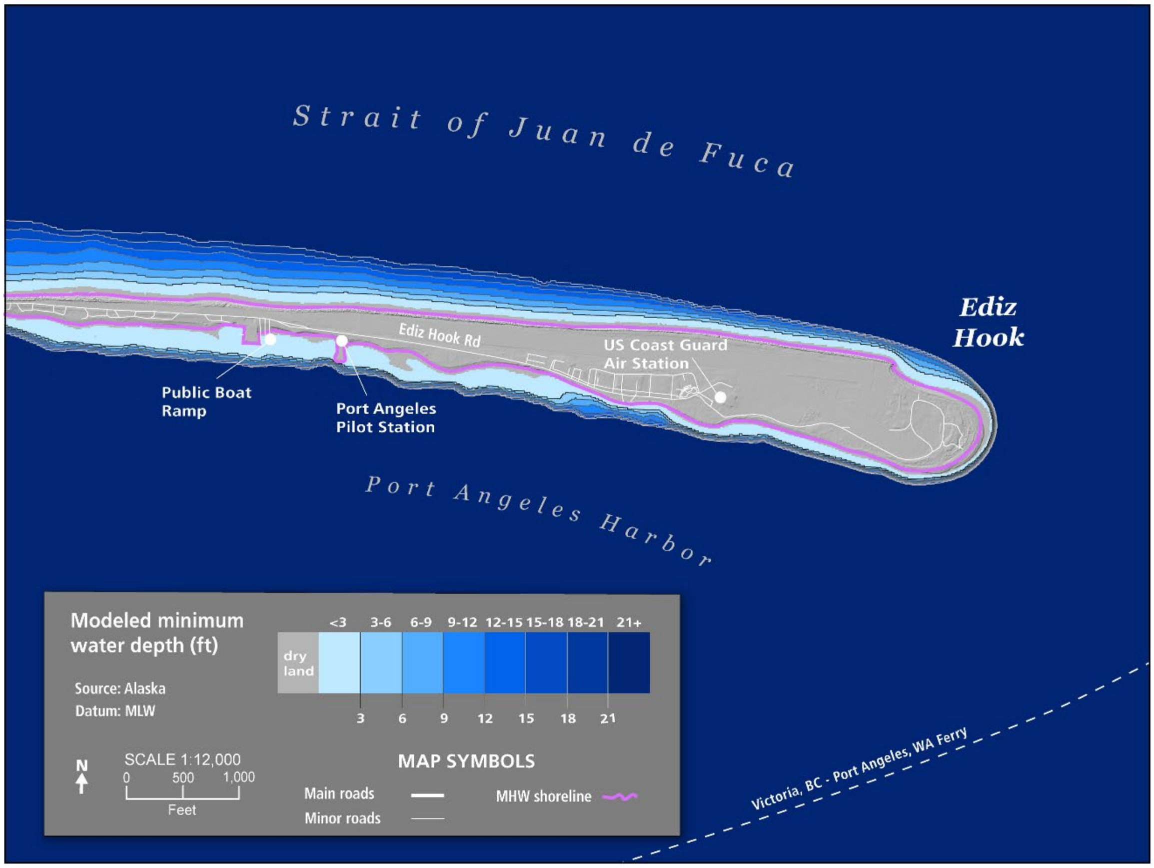


Figure 35. Modeled minimum water depths around the tip of the Ediz Hook from the tsunami generated by the Alaska Aleutian Subduction Zone earthquake scenario. Light blue colors represent water depths of 0 – 3 feet, with depths increasing by 3 feet for each respective darker shade of blue. Tidal datum: Mean Low Water. Model resolution: 1/9th arc-second (3 m).

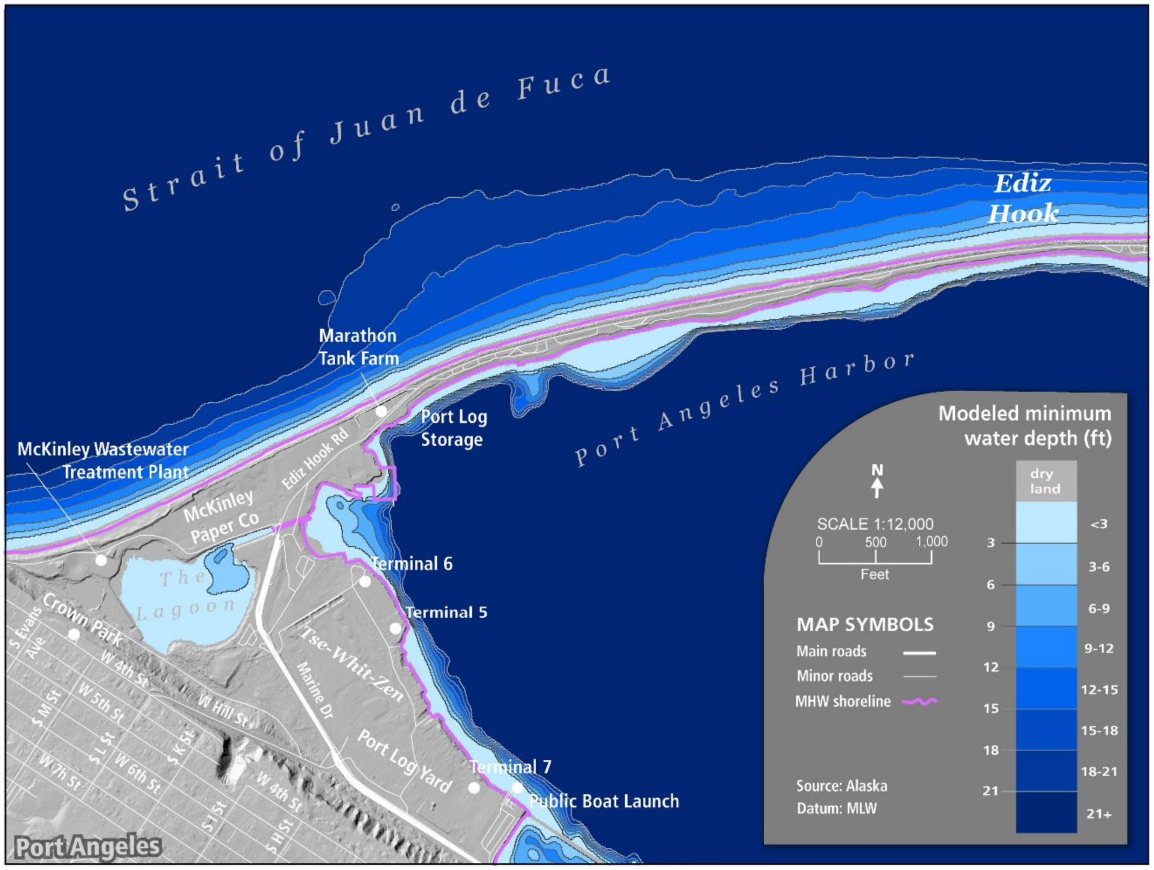


Figure 36. Modeled minimum water depths around the base of the Ediz Hook from the tsunami generated by the Alaska Aleutian Subduction Zone earthquake scenario. Light blue colors represent water depths of 0 – 3 feet, with depths increasing by 3 feet for each respective darker shade of blue. Tidal datum: Mean Low Water. Model resolution: 1/9th arc-second (3 m).

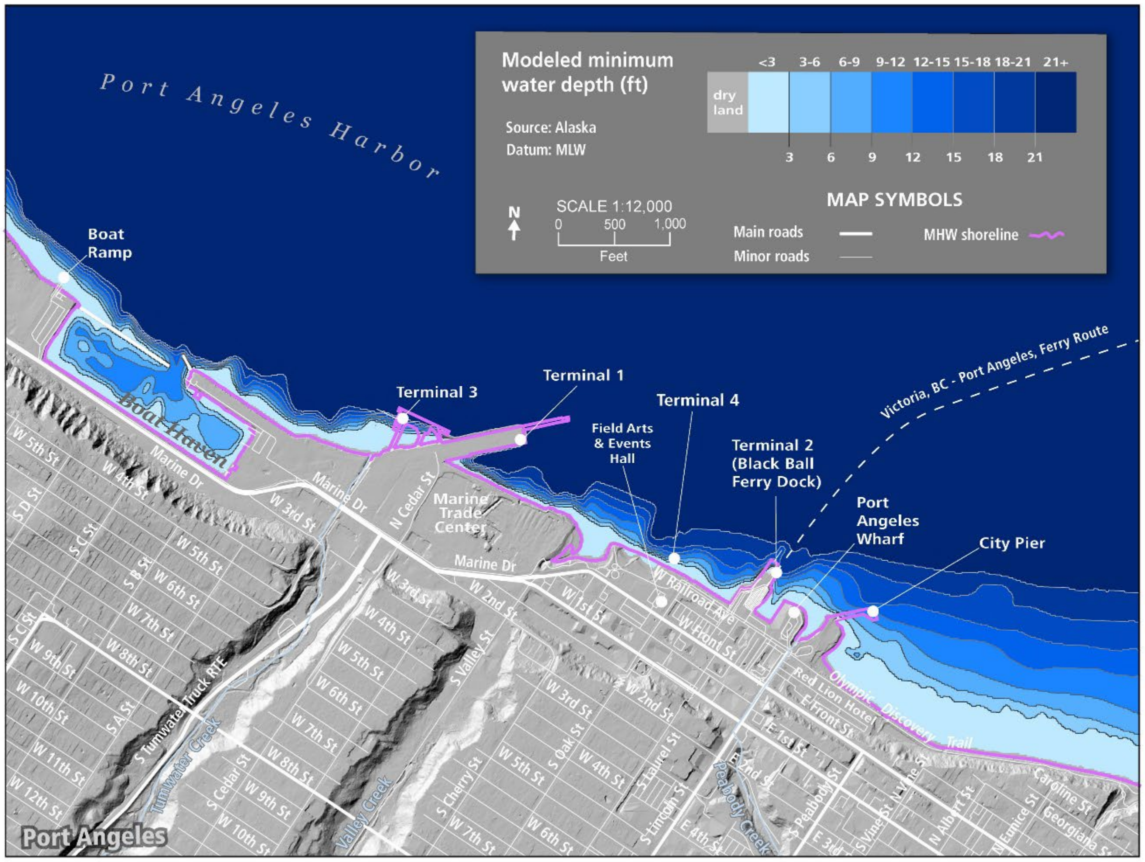


Figure 37. Modeled minimum water depths along the Port Angeles waterfront from the tsunami generated by the Alaska Aleutian Subduction Zone earthquake scenario. Light blue colors represent water depths of 0 – 3 feet, with depths increasing by 3 feet for each respective darker shade of blue. Tidal datum: Mean Low Water. Model resolution: 1/9th arc-second (3 m).

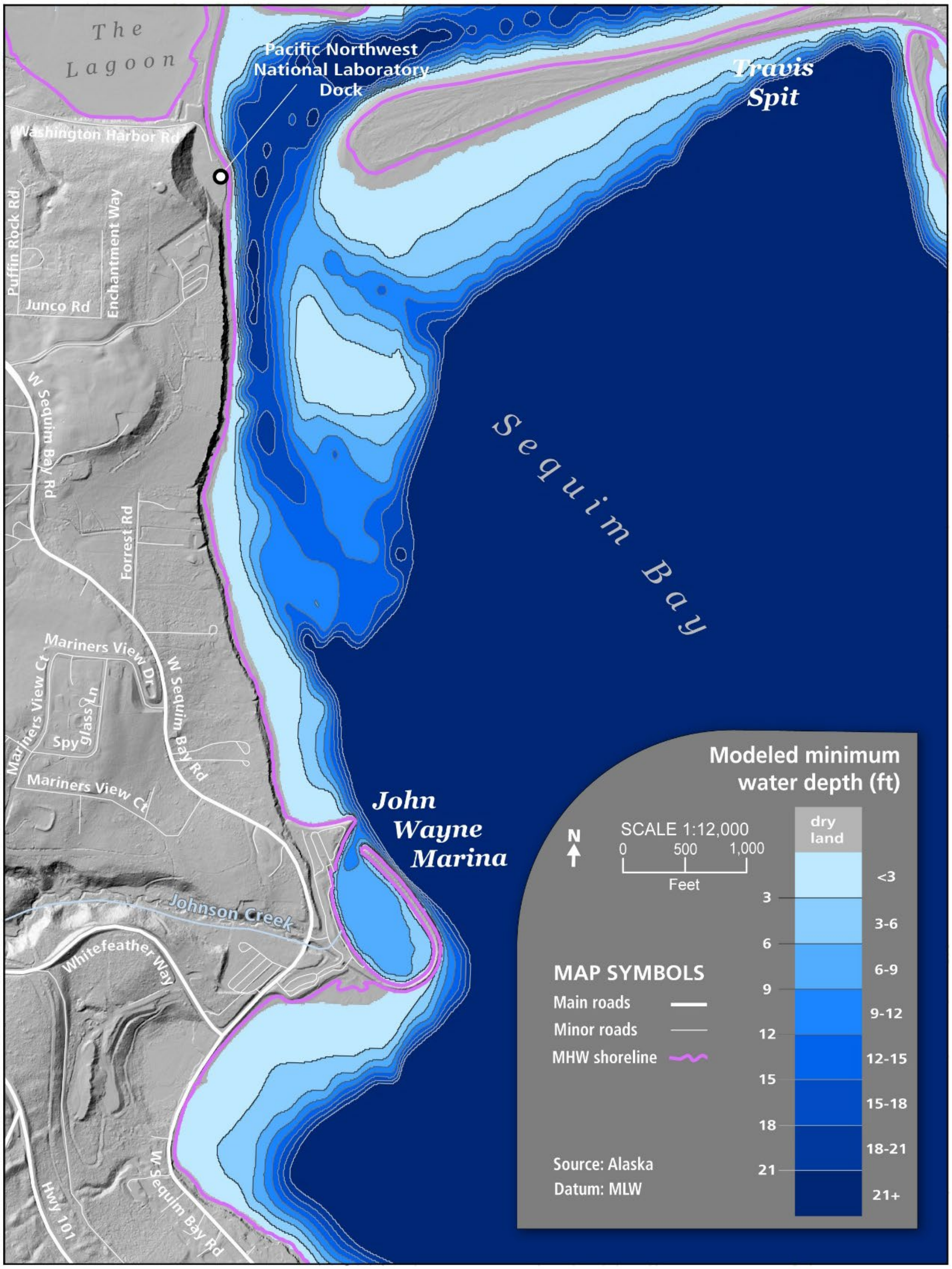


Figure 38. Modeled minimum water depths at the entrance to Sequim Bay including the John Wayne Marina from the tsunami generated by the Alaska Aleutian Subduction Zone earthquake scenario. Light blue colors represent water depths of 0 – 3 feet, with depths increasing by 3 feet for each respective darker shade of blue. Tidal datum: Mean Low Water. Model resolution: 1/9th arc-second (3 m).

Cascadia Subduction Zone (CSZ)

Compared to the AASZ scenario, there will be significantly more drawdown for the modeled Cascadia Subduction Zone (CSZ) scenario, increasing the risk to infrastructure and the environment. At the tip of Ediz Hook, any USCG or Port Angeles Pilots left at their docks when water levels recede may be grounded as water levels are estimated to drop on the south side of Ediz Hook to between 0 – 3 feet of water (Figure 39). For the Port Angeles Boat Haven, minimum water levels for this modeled scenario show that the entire eastern floats, nearly all the central floats, and about half of the western floats will be at water depths between 0 – 3 feet, leaving the majority of vessels grounded and exposed to incoming waves (Figure 41). These heightened impacts extend further away from the shoreline than the modeled AASZ scenario. Of greater concern in the CSZ scenario is the minimum water depths modeled at Terminal 2 (leased to the Black Ball ferry), where 0 – 3 feet of water remaining may impact the ferry's ability to avoid grounding and damage from inundating waves. Additionally, all port terminals outside of terminal 1 could be subject to water depths of 0 – 3 feet, heavily impacting any vessels that are tied up (Figures 40 and 41).

In the John Wayne Marina, there is not a significant difference in the drawdown modeling between the two scenarios. The model shows that the marina will maintain water depths between 6 – 9 feet throughout the marina, with 3 – 6 feet of water on the eastern edge (Figure 42). Similarly, The small island in Sequim Bay maintains a similar impact on minimum water depths between scenarios, creating hazards for boaters who are unaware or trying to navigate the rapid water level changes in a tsunami. While Sequim Bay sees a greater area of water receding away from the shoreline, there are minimal expected impacts to existing port-owned infrastructure.

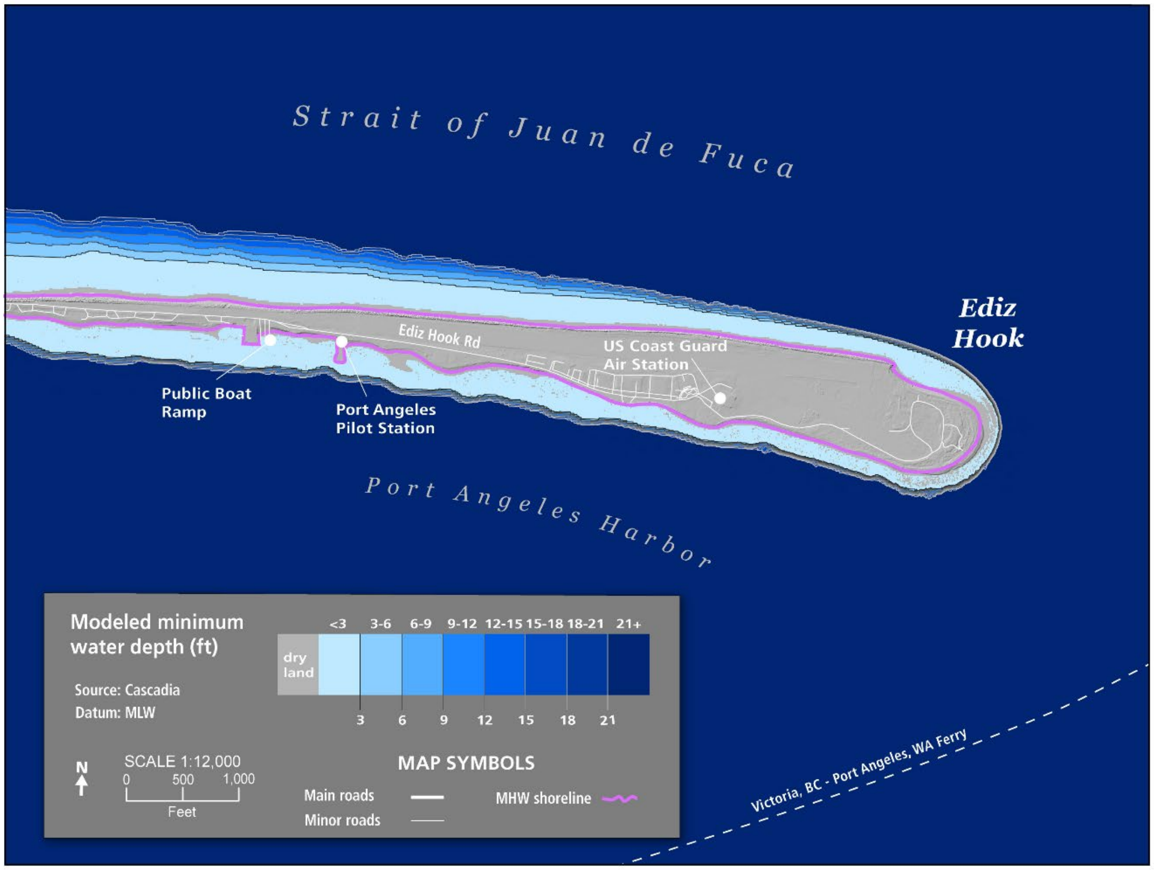


Figure 39. Modeled minimum water depths around the tip of the Ediz Hook from the tsunami generated by the Cascadia Subduction Zone earthquake scenario. Light blue colors represent water depths of 0 – 3 feet, with depths increasing by 3 feet for each respective darker shade of blue. Tidal datum: Mean Low Water. Model resolution: 1/9th arc-second (3 m).

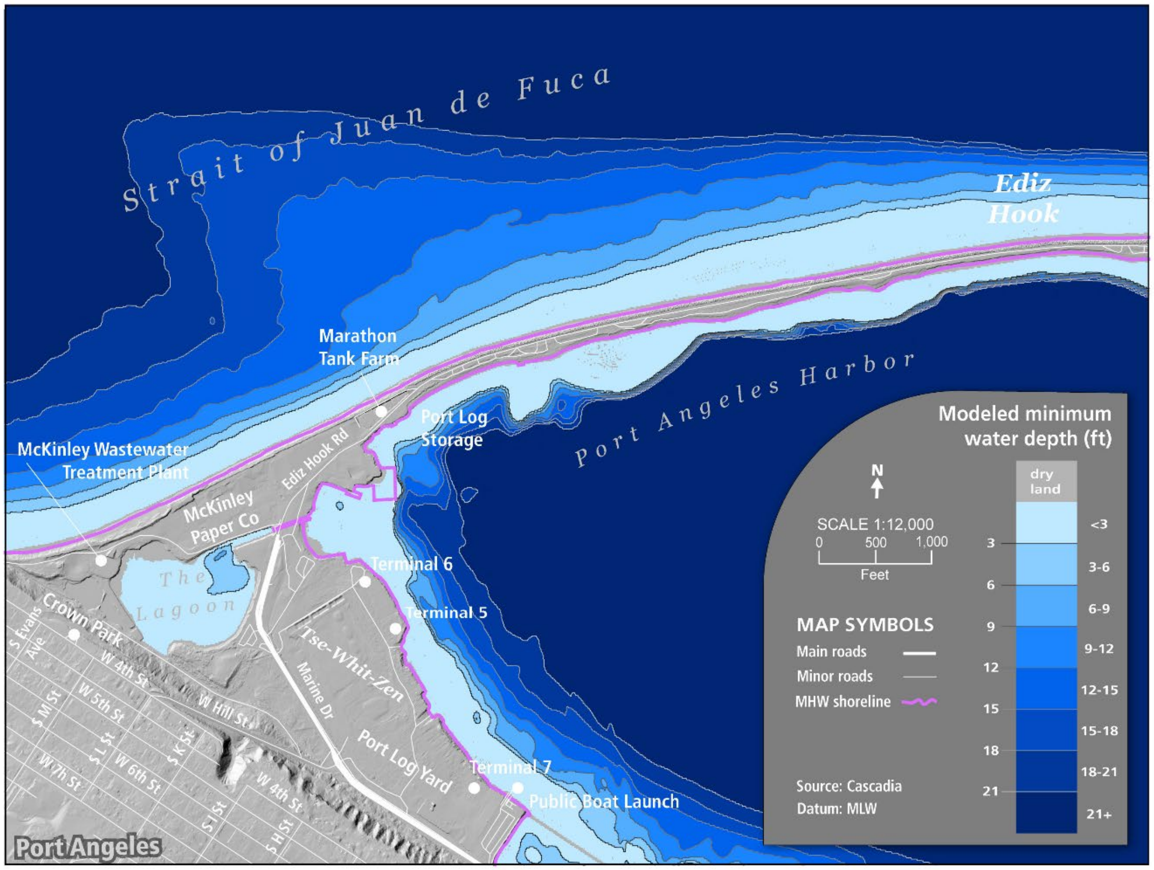


Figure 40. Modeled minimum water depths around the base of the Ediz Hook from the tsunami generated by the Cascadia Subduction Zone earthquake scenario. Light blue colors represent water depths of 0 – 3 feet, with depths increasing by 3 feet for each respective darker shade of blue. Tidal datum: Mean Low Water. Model resolution: 1/9th arc-second (3 m).

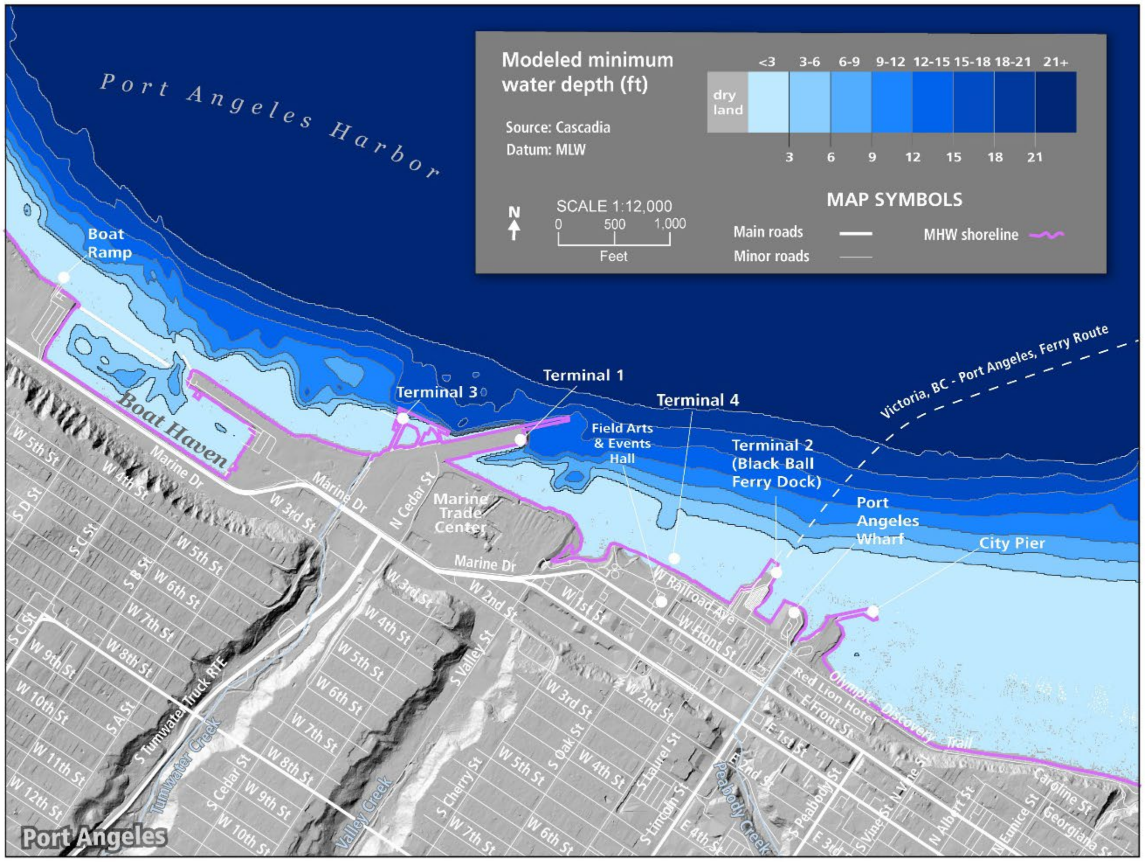


Figure 41. Modeled minimum water depths along the Port Angeles Waterfront from the tsunami generated by the Cascadia Subduction Zone earthquake scenario. Light blue colors represent water depths of 0 – 3 feet, with depths increasing by 3 feet for each respective darker shade of blue. Tidal datum: Mean Low Water. Model resolution: 1/9th arc-second (3 m).

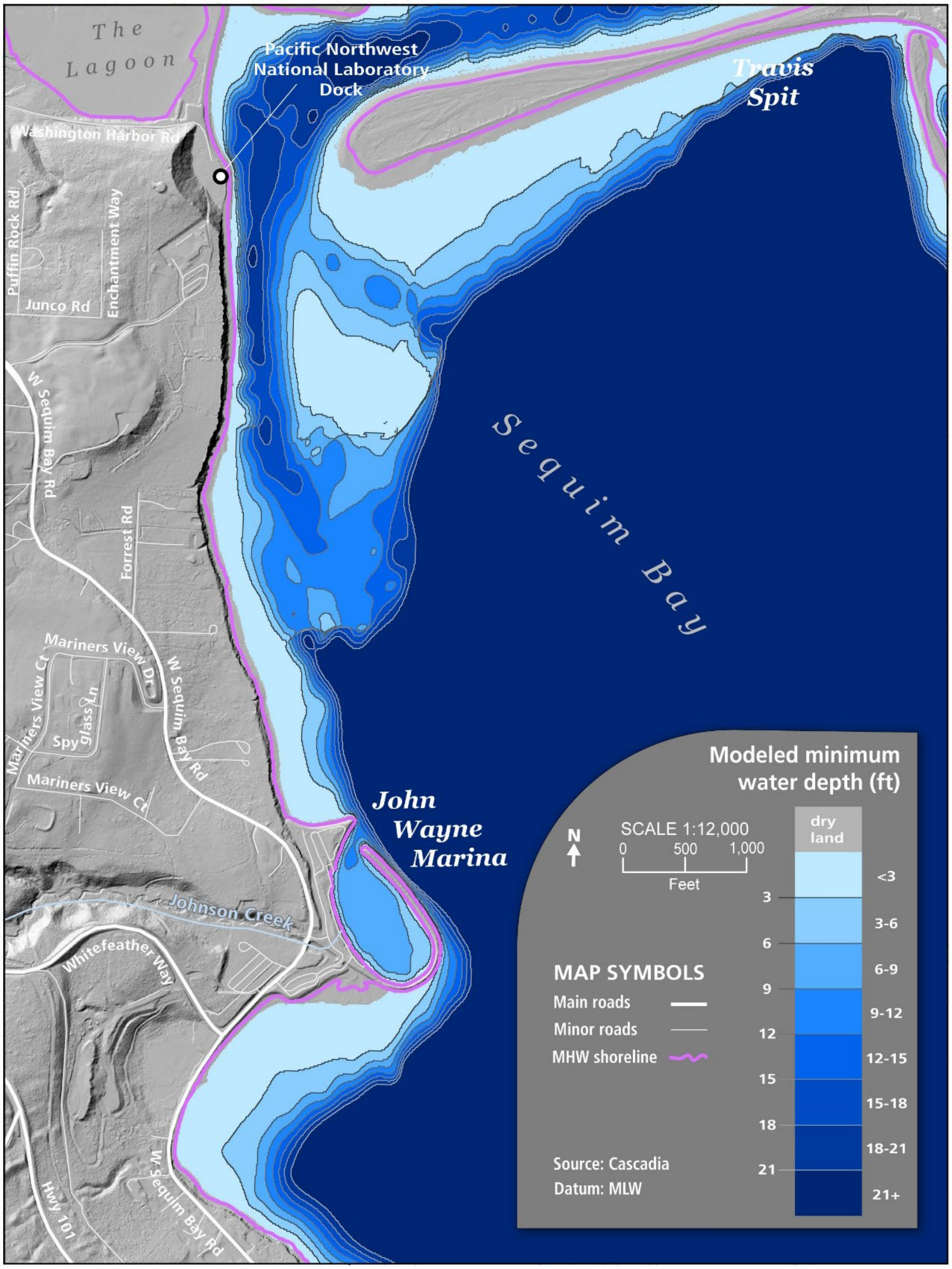


Figure 42. Modeled minimum water depths in the entrance to Sequim Bay including John Wayne Marina from the tsunami generated by the Cascadia Subduction Zone earthquake scenario. Light blue colors represent water depths of 0 – 3 feet, with depths increasing by 3 feet for each respective darker shade of blue. Tidal datum: Mean Low Water. Model resolution: 1/9th arc-second (3 m).

Tsunami Waveform Over Time

Synthetic tide gauges are an essential tool for visualizing how tsunamis progress over time. These graphical representations are useful for both response and mitigation efforts, as they provide insights into when and how long maximum wave heights, drawdowns, and increased current speeds may occur during a tsunami.

In this study, each synthetic tide gauge records wave heights (Figures 43-48) and current speeds (Figures 49-54) over 14 hours for the Alaska Aleutian Subduction Zone and 10 hours for the Cascadia Subduction Zone (CSZ) scenario. Both high tide (Mean High Water) and low tide (Mean Low Water) conditions are simulated to capture how wave heights vary with changing tides. It's important to note that wave amplitudes often increase as water depths decrease, meaning shallower areas near the shore could expect larger waves than the models show. Observations from synthetic gauges place in water depths of around 33 feet (10 meters) or shallower have been shown in various studies to improve the representativity of the near-shore wave field and thereby enhance prediction of onshore runup, especially when local bathymetry and wave transformation conditions are well characterized (Fiorentino et al., 2021; Medellin et al., 2016).

While the simulations cover 14 and 10 hours for the AASZ and CSZ scenarios respectively, real-world tsunami effects could last longer, and even minor waves or increased currents could delay response and recovery operations. For specific information on wave arrivals, summary tables (1 and 2) provide detailed timings from each modeled scenario at different wave height thresholds, including advisory and warning-level waves.

Sequim Bay (Entrance)

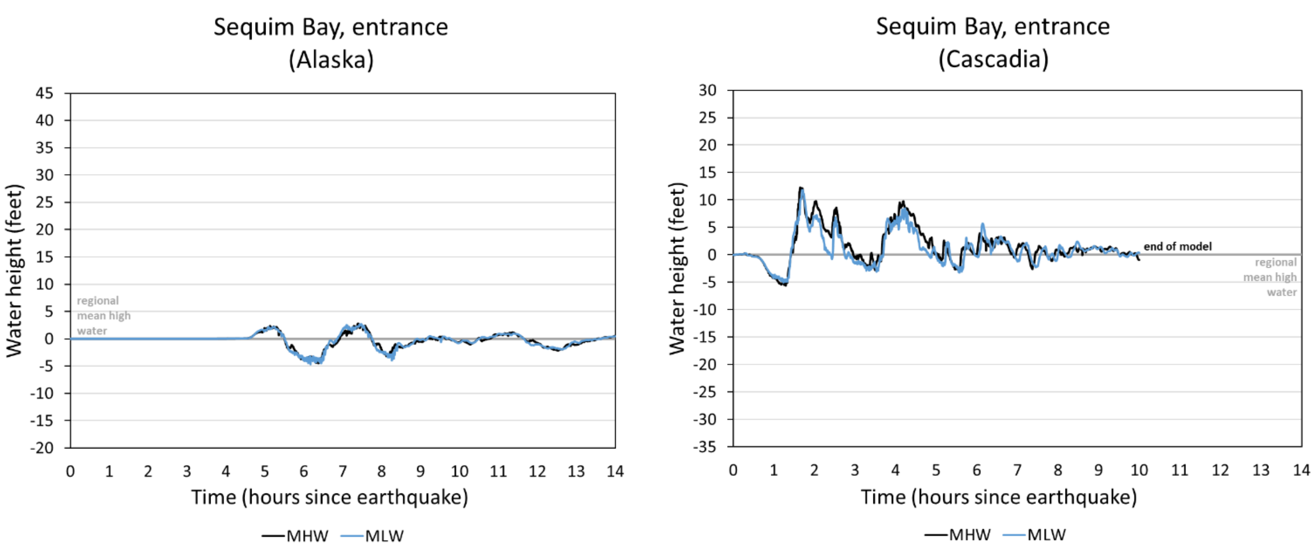


Figure 43: Modeled tsunami wave heights over time at the entrance to Sequim Bay simulated synthetic tide gauge (gauge #2) from the Alaska Aleutian Subduction Zone (AASZ, left) and Cascadia Subduction Zone (CSZ, right) earthquake scenarios. Black and blue lines represent simulations using the Mean High Water or Mean Low Water tidal datum, respectively.

John Wayne Marina (Center)

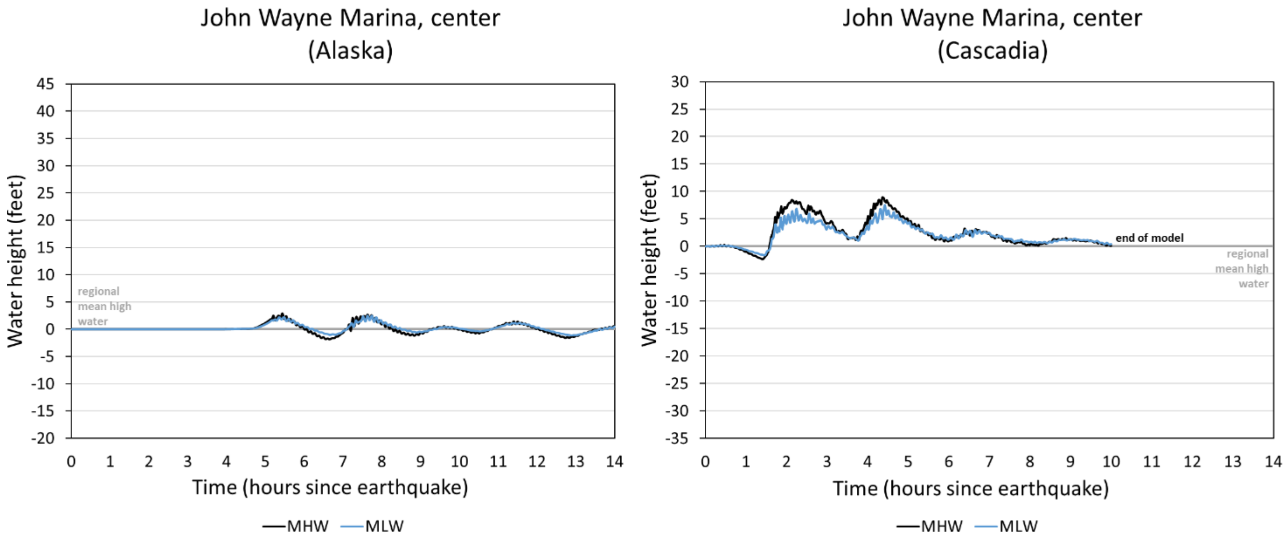


Figure 44: Modeled tsunami wave heights over time at a John Wayne Marina simulated synthetic tide gauge (gauge #4) from the Alaska Aleutian Subduction Zone (AASZ, left) and Cascadia Subduction Zone (CSZ, right) earthquake scenarios. Black and blue lines represent simulations using either the Mean High Water or Mean Low Water tidal datum, respectively.

Off the eastern edge of Ediz Hook

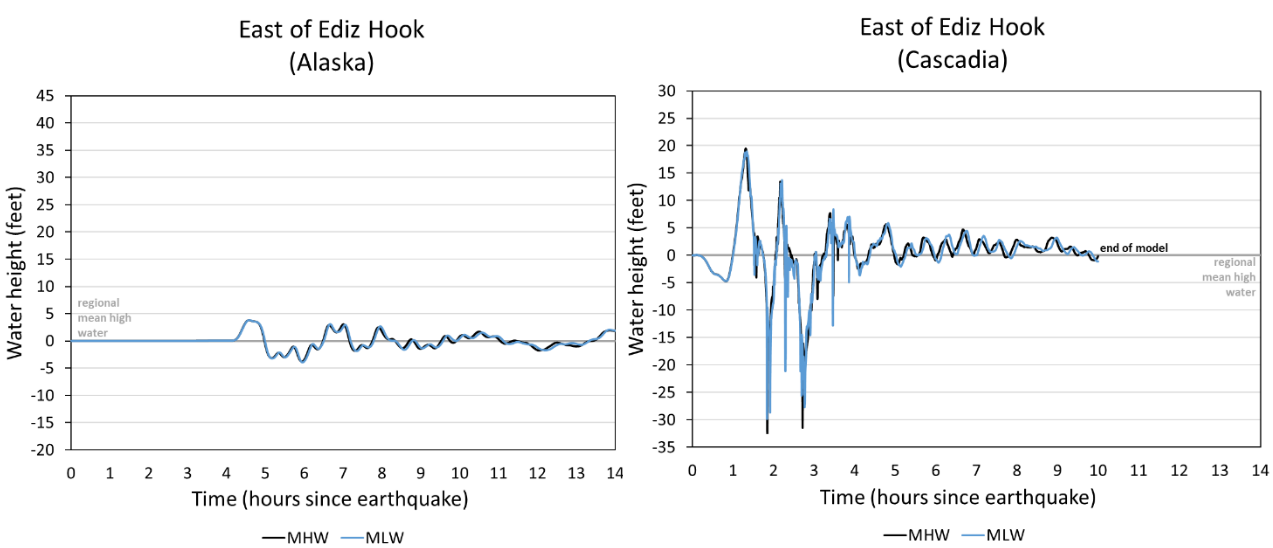


Figure 45: Modeled tsunami wave heights over time at the east of Ediz Hook simulated synthetic tide gauge (gauge #17) from the Alaska Aleutian Subduction Zone (AASZ, left) and Cascadia Subduction Zone (CSZ, right) earthquake scenarios. Black and blue lines represent simulations using either the Mean High Water or Mean Low Water tidal datum, respectively.

Port Angeles Harbor (West)

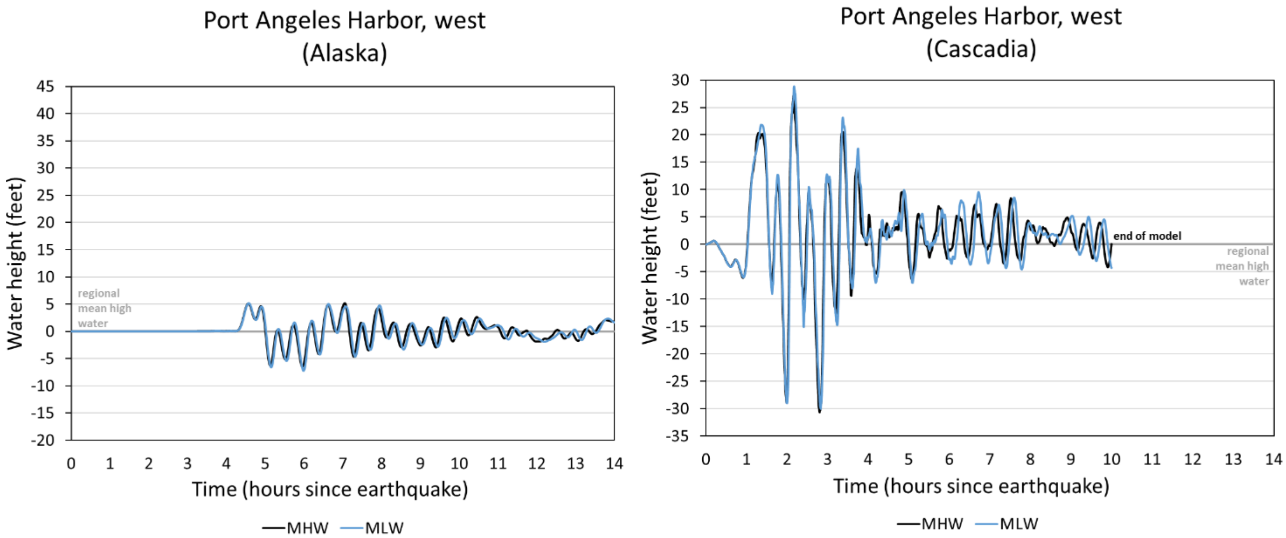


Figure 46: Modeled tsunami wave heights over time at the western edge of Port Angeles Harbor simulated synthetic tide gauge (gauge #22) from the Alaska Aleutian Subduction Zone (AASZ, left) and Cascadia Subduction Zone (CSZ, right) earthquake scenarios. Black and blue lines represent simulations using either the Mean High Water or Mean Low Water tidal datum, respectively.

Port Angeles Boat Haven (Center)

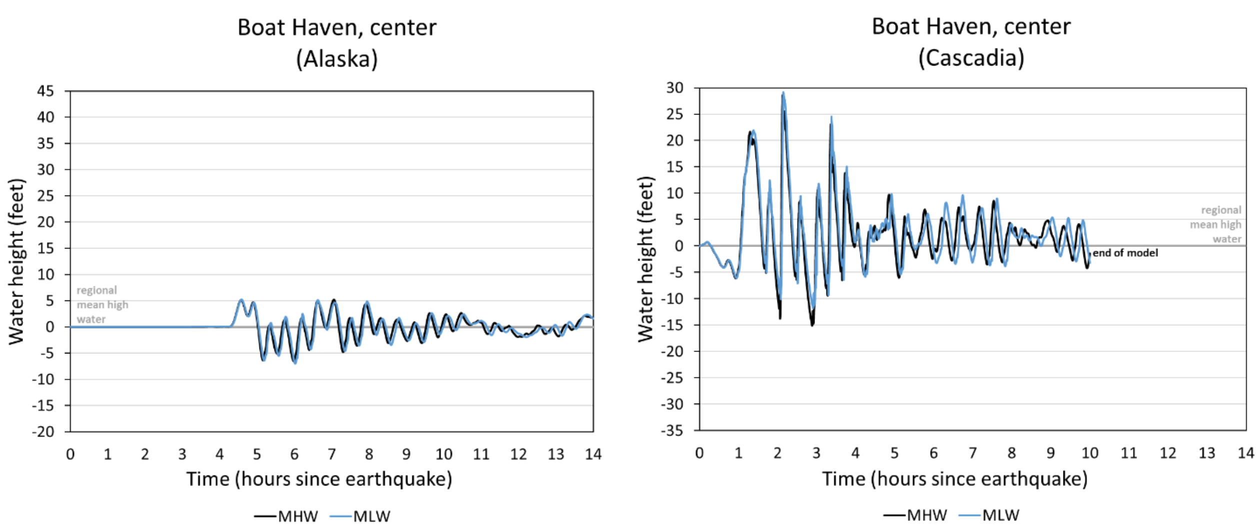
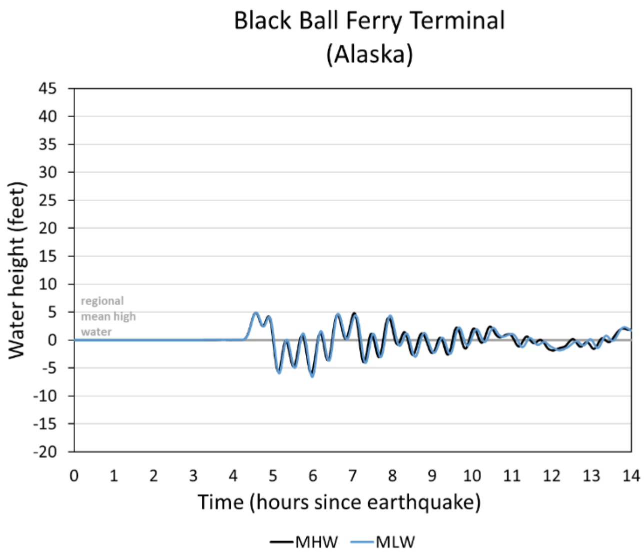


Figure 47. Modeled tsunami wave heights over time at the Port Angeles Boat Haven simulated synthetic tide gauge (gauge #31) from the Alaska Aleutian Subduction Zone (AASZ, left) and Cascadia Subduction Zone (CSZ, right) earthquake scenarios. Black and blue lines represent simulations using either the Mean High Water or Mean Low Water tidal datum, respectively.

Black Ball Ferry Terminal (Terminal 2)



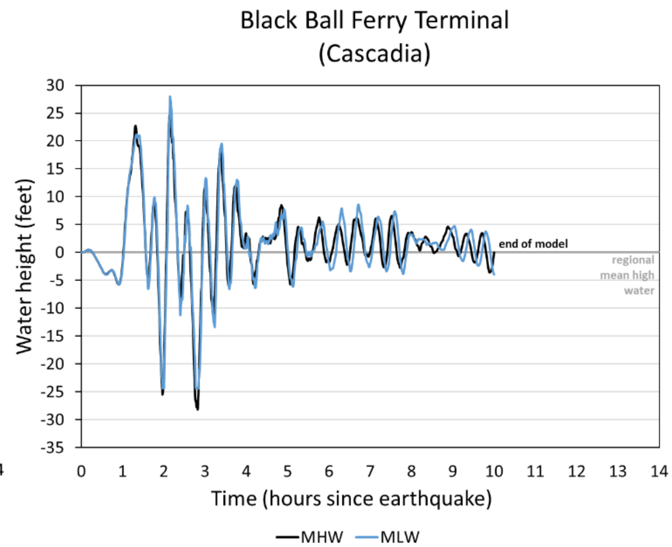


Figure 48. Modeled tsunami wave heights over time at the Black Ball Ferry Terminal (Terminal 2) simulated synthetic tide gauge (gauge #39) from the Alaska Aleutian Subduction Zone (AASZ, left) and Cascadia Subduction Zone (CSZ, right) earthquake scenarios. Black and blue lines represent simulations using either the Mean High Water or Mean Low Water tidal datum, respectively.

Wave Current Speeds through Time

Sequim Bay (Entrance)

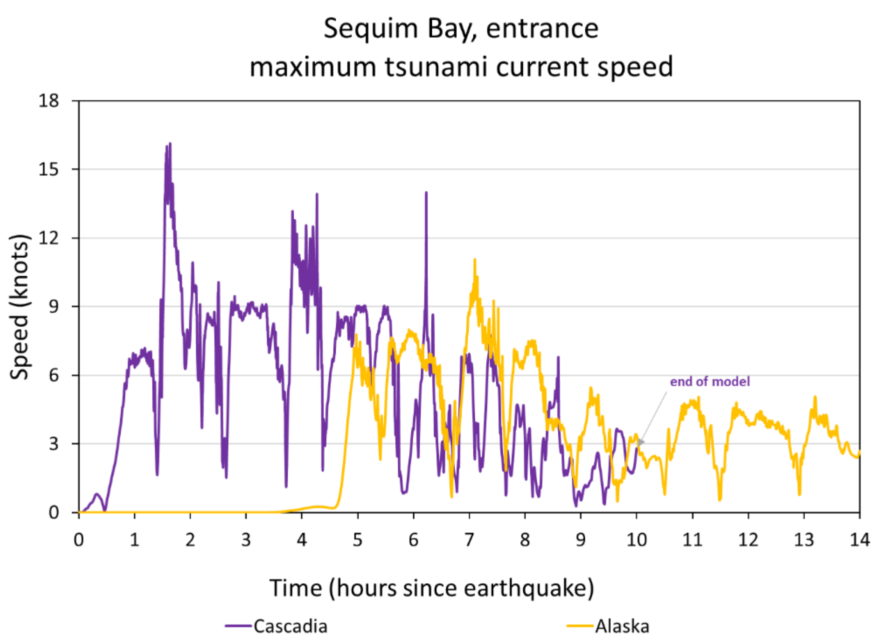


Figure 49. Modeled tsunami current speed over time at the entrance to Sequim Bay simulated synthetic tide gauge (gauge #2). Purple and yellow lines represent simulations from the Cascadia Subduction Zone and Alaska Aleutian Subduction Zone earthquake scenarios, respectively. Reported speeds are maximum values generated from either the mean high water or mean low water simulations.

John Wayne Marina (Center)

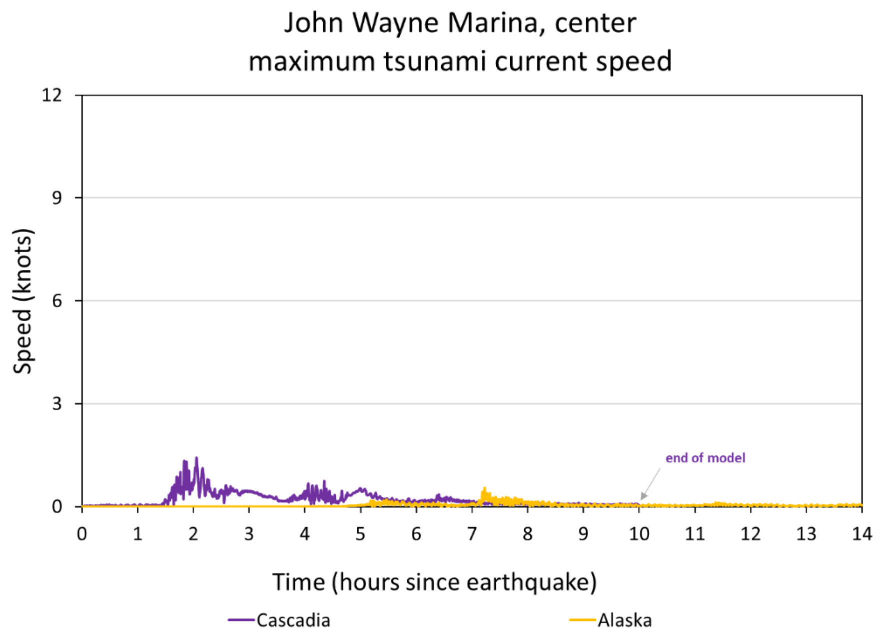


Figure 50. Modeled tsunami current speed over time at the John Wayne Marina simulated synthetic tide gauge (gauge #4). Purple and yellow lines represent simulations from the Cascadia Subduction Zone and Alaska Aleutian Subduction Zone earthquake scenarios, respectively. Reported speeds are maximum values generated from either the mean high water or mean low water simulations.

Off the eastern edge of Ediz Hook

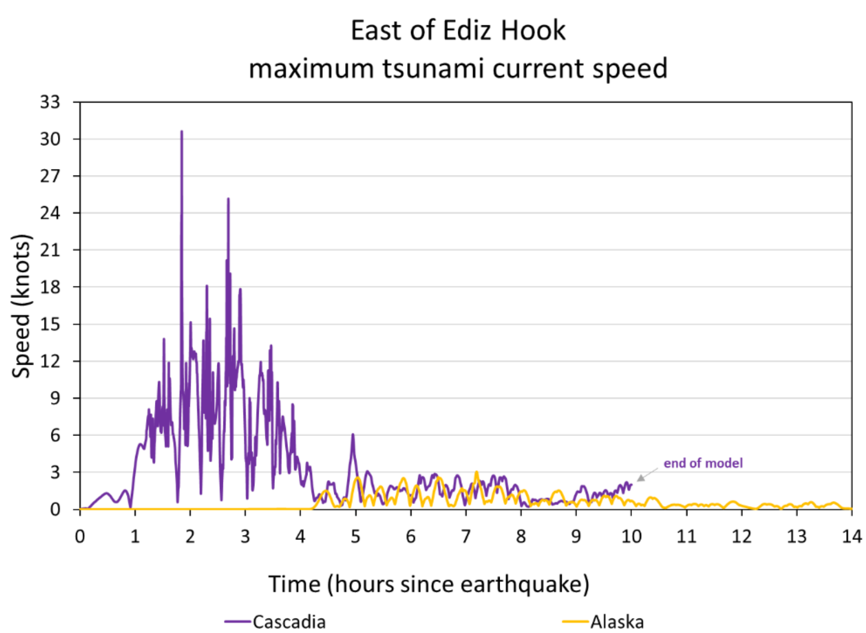


Figure 51: Modeled tsunami current speed over time eastern edge of Ediz Hook simulated synthetic tide gauge (gauge #17). Purple and yellow lines represent simulations from the Cascadia Subduction Zone and Alaska Aleutian Subduction Zone earthquake scenarios, respectively. Reported speeds are maximum values generated from either the mean high water or mean low water simulations.

Port Angeles Harbor (West)

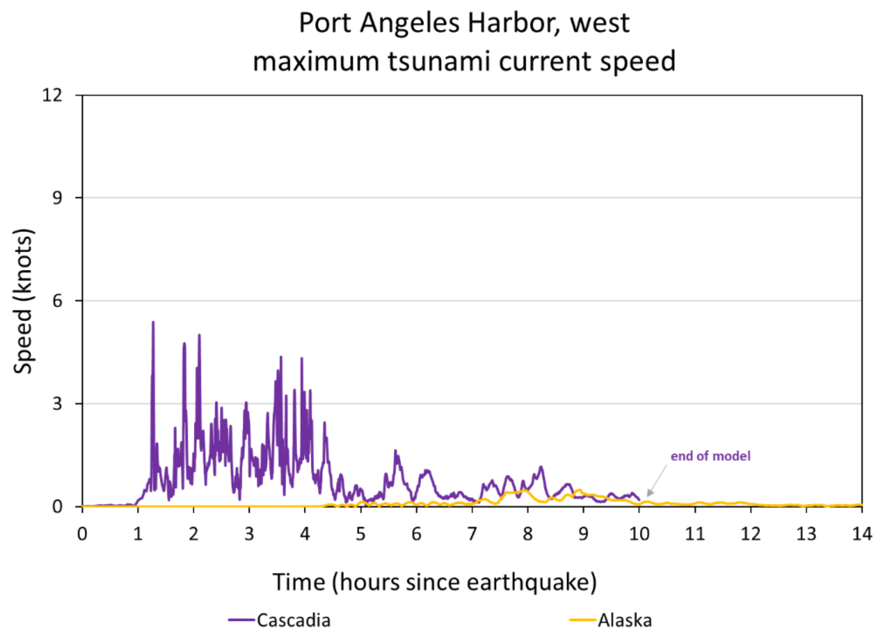


Figure 52: Modeled tsunami current speed over time at the western edge of Port Angeles Harbor simulated synthetic tide gauge (gauge #22). Purple and yellow lines represent simulations from the Cascadia Subduction Zone and Alaska Aleutian Subduction Zone earthquake scenarios, respectively. Reported speeds are maximum values generated from either the mean high water or mean low water simulations.

Port Angeles Boat Haven (Center)

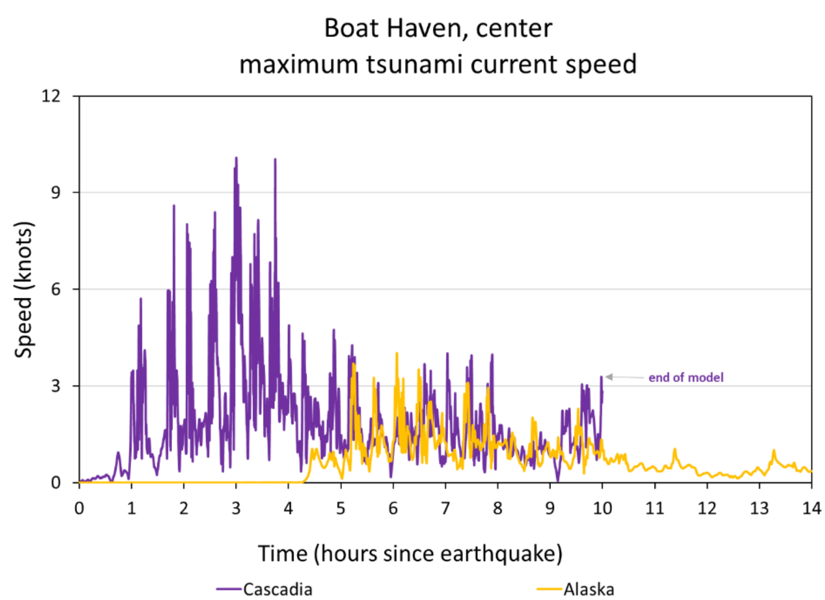


Figure 53. Modeled tsunami current speed over time at the Port Angeles Boat Haven simulated synthetic tide gauge (gauge #31). Purple and yellow lines represent simulations from the Cascadia Subduction Zone and Alaska Aleutian Subduction Zone earthquake scenarios, respectively. Reported speeds are maximum values generated from either the mean high water or mean low water simulations.

Black Ball Ferry Terminal (Terminal 2)

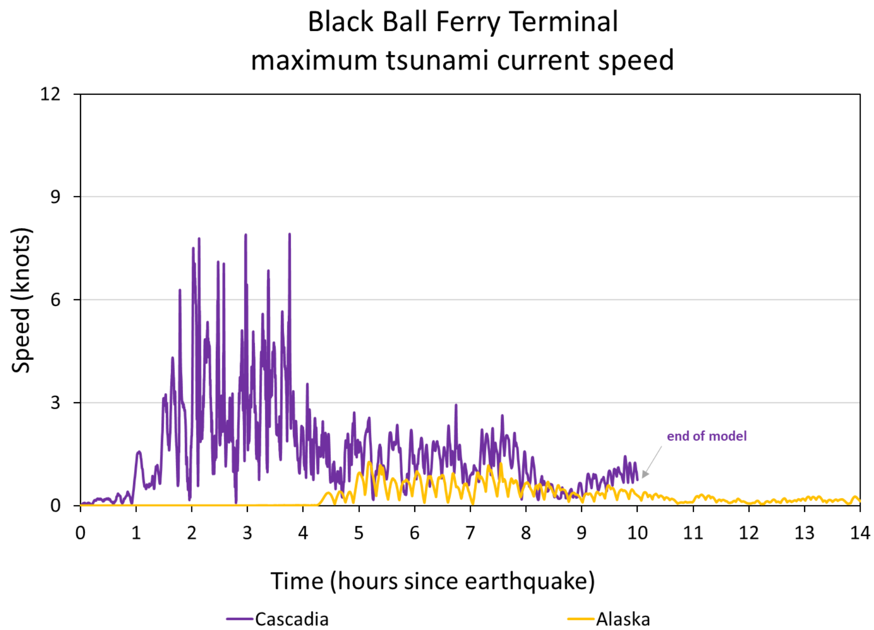


Figure 54. Modeled tsunami current speed over time at the Black Ball Ferry Terminal (Terminal 2) simulated synthetic tide gauge (gauge #39). Purple and yellow lines represent simulations from the Cascadia Subduction Zone and Alaska Aleutian Subduction Zone earthquake scenarios, respectively. Reported speeds are maximum values generated from either the mean high water or mean low water simulations.

Wave Arrival Time Summary Tables

Tables 1 and 2 below provide a summary of wave arrival times at various defined wave height thresholds. These wave arrival times are critical for informing emergency response feasibility and capability. By understanding the timing of different wave heights, decision-makers can better assess the potential impact and make informed choices about response actions. These charts should be thoroughly reviewed when developing and documenting Standard Operating Procedures (SOPs) to ensure that all response-related actions are timed appropriately and align with the evolving conditions of a tsunami. Note that the first wave in the tsunami sequence may not represent this maximum. When reading the tables, refer to the following definitions:

TFirstAdvis (First Advisory)*:*

- This marks the time when offshore wave heights first exceed 1 foot, triggering an advisory-level alert as per the National Tsunami Warning Center (NTWC) guidance.

TFirstDraw (First Drawdown)*:*

- This is the time when offshore wave heights first fall below 1 foot, indicating the onset of drawdown conditions, which is considered advisory-level according to NTWC standards.

TFirstWarn (First Warning)*:*

- Represents the time when offshore wave heights exceed 3 feet, marking the arrival of a warning-level wave as classified by the National Tsunami Warning Center.

***TMax (Maximum Wave Height)*:**

- The time at which the highest wave in the tsunami sequence occurs. Note: This may not always be the first wave of the event.

***TMin (Maximum Drawdown)*:**

- Indicates the time when the greatest drawdown (i.e., the lowest water level) is reached during the tsunami. Like TMax, this might not correspond to the first wave.

Alaska Aleutian Subduction Zone (AASZ)

Table 1 shows a summary of approximate tsunami wave arrival times, in minutes, using different wave height thresholds from the Alaska Aleutian Subduction Zone (AASZ) earthquake scenario.

Table 1. AASZ scenario, timing since start of earthquake (mins)						
Location	**Gauge Number**	**TFirst Advis**	**TFirst Draw**	**TFirst Warn**	**TMax**	**TMin**
Sequim Bay (Entrance)	2	286	333	n/a*	444	382
John Wayne Marina (Center)	4	298	378	n/a*	326	399
Off the eastern edge of Ediz Hook	17	259	300	268	275	356
Port Angeles Harbor (West)	22	262	301	267	423	357
Port Angeles Boat Haven (Center)	31	262	302	267	423	359
Black Ball Ferry Terminal (Terminal 2)	39	262	301	267	274	357

*water levels at the tide gauge do not exceed the warning level threshold of 0.9144 meters (or 3 feet) as outlined in the Technical Report.

Cascadia Subduction Zone (CSZ)

Table 2 shows a summary of tsunami wave arrival times, in minutes, using different wave height thresholds from the Cascadia Subduction Zone (CSZ) earthquake scenario.

Table 2. CSZ scenario, timing since start of earthquake (mins)						
Location	**Gauge Number**	**TFirst Advis**	**TFirst Draw**	**TFirst Warn**	**TMax**	**TMin**
Pacific NW National Laboratory Dock	2	86	42	91	99	77
John Wayne Marina (Center)	4	96	61	100	262	84
Off the eastern edge of Ediz Hook	17	61	20	63	79	111
Port Angeles Harbor (West)	22	62	22	63	129	169
Port Angeles Boat Haven (Center)	31	63	22	64	127	173
Black Ball Ferry Terminal (Terminal 2)	39	62	21	63	129	169

Section 4: Tsunami Response Guidance

In the crucial moments following the onset of an emergency, the effectiveness of response actions plays a pivotal role in safeguarding lives and mitigating property damage. The initial minutes and hours are particularly decisive, demanding a well-coordinated and swift approach. It is imperative to have a clear understanding of the recommended response actions and the individuals or entities responsible for executing them. By examining and learning from the response strategies implemented in various states, such as Alaska and Hawaii, insights into effective tsunami response actions can be gleaned. These include timely evacuation protocols, communication strategies to disseminate accurate information swiftly, and the establishment of incident command. The synthesis of lessons learned from diverse geographical contexts enhances the collective capacity to respond to tsunamis and other emergencies, fostering a more resilient and proactive approach to emergency management.

Tsunami Response Actions

Below is a list of various potential tsunami emergency response actions for the maritime community that have been implemented in other states, offering insights into their practicality, implementation, and impact. From evacuation procedures to communication strategies, each description aims to equip communities and key decision makers in emergency response with a nuanced understanding of the diverse measures available to safeguard lives and minimize the impact of tsunamis.

In the comprehensive evaluation of tsunami response actions for the Port of Port Angeles, each potential action was evaluated based on its feasibility, classifying them as either 'Feasible,' 'Needs Review,' or 'Not Feasible.' This critical analysis considers the unique characteristics and vulnerabilities for the Port Angeles Harbor and Sequim Bay areas. The applicability of these response actions extends to scenarios involving both an Alaska Aleutian Subduction Zone (AASZ) and a Cascadia Subduction Zone (CSZ) earthquake-generated tsunami.

The 'Feasible' designation implies that the response action is deemed practical and implementable within the context of the local geography, infrastructure, and resources. Actions categorized as 'Needs Review' may require further scrutiny and adaptation to address specific considerations unique to the Port Angeles Harbor and Sequim Bay areas. Conversely, response actions labeled as 'Not Feasible' may be challenging to execute or may pose inherent risks that outweigh their potential benefits in the context of life safety and protecting property.

This nuanced assessment provides an understanding of the viability and appropriateness of each response action, facilitating a targeted and customized approach to tsunami preparedness and mitigation for the Port Angeles Harbor and John Wayne Marina in the face of potential seismic events from both the Alaska Aleutian and Cascadia Subduction Zones.

Each response action in the following section is structured as follows: background on the action, feasibility determination, and reasoning gathered from conversations at workshops and check-in meetings. A summary of the feasibility of various response actions is provided in Table 3 below.

Tsunami Response Actions	Feasibility for the Port of Port Angeles
Shut Down Port Infrastructure Before Tsunami Arrives	Feasible
Personal Floatation Devices/Vests for Port Staff	Feasible
Informing and Coordinating with Key First Responders During a Tsunami	Feasible
Remove or Secure Hazardous Materials Used or Owned by the Port	Feasible
Identify Boat Owners/Individuals Who Live Aboard Vessels and Establish Notification Processes	Feasible
Restrict Traffic Entering the Port by Land and Aid in Traffic Evacuation	Feasible
Pre-Stage Emergency Equipment Outside Affected Area	Feasible
Pre-Identify Personnel to Assist in Rescue, Survey, and Salvage Efforts	Feasible
Secure Moorings of Port Owned Vessels	Feasible
Evacuate Public/Vehicles from Waterfront Areas	Needs Review
Activate Incident Command at Evacuation Sites	Needs Review
Activate Mutual Aid System as Necessary	Needs Review
Reposition Ships Within the Port	Not Feasible
Remove Small Vessels from the Water	Not Feasible
Remove Buoyant Assets Out of and Away from the Water	Not Feasible
Restrict Boats from Moving and Prevent Ships from Entering the Port During a Tsunami	Not Feasible

Table 3. A summary of the evaluation of 16 actions for the Port of Port Angeles to consider in tsunami response. Each action was assigned a feasibility category based on documents and expertise provided by key Port of Port Angeles staff and their partners.

Shut Down Port Infrastructure Before Tsunami Arrives

The challenges in tsunami recovery go beyond repairing docks and clearing debris from the water. Torn fuel or sewage pump out lines can leak into the water during and after the tsunami, leading to extensive environmental cleanup. Additionally, if facilities are inundated while the power systems are on, this could cause dangerous conditions for responders and increased damage to those systems. Having procedures and plans in place to shut down infrastructure, including water supply valves and power to facilities, quickly and efficiently in the event of a tsunami can help mitigate impacts. Ensuring there are shutoffs in appropriate locations that are easy to access and clearly labeled, as well as remote shutoffs where possible, can save time and improve the likelihood of success.

This action is feasible

The Port of Port Angeles has an on-site 24/7 security team that is responsible for monitoring the property and ensuring the safety and security of the site. All facilities on-site, including both the Port Angeles Boat Haven and the John Wayne Marina, require keycard access for entry, ensuring only those with approval have access to the facilities. Security personnel are trained in the steps required to shut off power for the facilities. Given the 24/7 presence of security staff, actions to secure the facilities and to shut off power can be handled quickly upon either receipt of a tsunami alert or immediately after earthquake shaking stops, even if outside of typical operating hours for the port. To further improve their ability to reduce the impact of earthquake shaking at port facilities, the Port should work with the Pacific Northwest Seismic Network (PNSN) to evaluate the viability of incorporating the ShakeAlert system into their operations. ShakeAlert is a system that can provide seconds of warning before earthquake shaking starts. By integrating ShakeAlert into their existing systems, it's possible that the existing fuel tanks could be automatically shut down upon detection of an earthquake. The Port should also incorporate tsunami risk and critical alerting information into their security trainings, with support from Clallam County Emergency Management and Washington Emergency Management Division (WA EMD).

The primary challenge that comes with shutting down power to facilities is to ensure that known liveaboards are evacuated before power shutoff to ensure that they can get to safety with ample time before waves arrive. These actions are addressed in other sections.

Personal Floatation Devices/Vests for Port Staff

Ideally, all Port staff will have evacuated to high ground and thus away from danger before the first waves of either a local or distant tsunami arrive. However, during a local source tsunami there may not be enough time to reach high ground, and during a distant source tsunami staff may remain in the inundation zone to perform response activities. In such an event, having floatation devices or vests easily available for Port staff can reduce casualties. Any persons in the inundation zone when waves arrive are in extreme danger and while floatation devices will not guarantee safety, they at least offer a better chance of survival.

This action is feasible

The Port has life vests available at both marinas that staff can utilize during an emergency, including publicly available ones laid out at the "Kids Don't Float" sign at John Wayne Marina. Staff are responsible for keeping track of their own life vests with a small supply of extras at the guard shack at the marine terminal. To ensure the safety of visitors and liveaboards alike, the Port should work with the boaters to ensure they have enough flotation devices for themselves and the capacity of their vessel.

Informing and Coordinating with Key First Responders During a Tsunami

Local first responders play a key role in alerting, evacuation, road closures, incident management, and post-tsunami response. Ensuring that responders are aware of both the imminent risk to the Port, its facilities, tenants, and users, and what tsunami response actions the Port is taking is essential for effective coordinated response and communication. This coordination can help save lives and property. Response capability for a local source tsunami is challenging given the short time before wave arrival, increased inundation, and higher current speeds, but there are still opportunities to coordinate. It is prudent to identify and practice communication and coordination processes between the

Port and first responders before the next tsunami and apply lessons learned. This will help avoid confusion or duplication of effort and will improve overall response capability.

This action is feasible

During distant tsunami events, Clallam County Emergency Management hosts conference calls with key partners within the county after gathering and verifying information during the hourly State Tsunami Coordination Call facilitated by Washington Emergency Management Division. The Port of Port Angeles and the local first responders, including the City of Port Angeles Emergency Manager, attend these calls. These conference calls are essential for the Port to gather critical decision-making information related to the tsunami threat such as expected wave arrival times, and to coordinate with local first responders on the call.

Beyond the county-led conference calls, the Port largely relies on unstructured communication processes to communicate with local first responders. This was echoed by local fire districts as well, who do not have any documented plans that outline how they would communicate with the Port throughout tsunami response – although they acknowledge that they would be in contact with the Port throughout a tsunami.

The Port should work with local first responders (both fire districts and law enforcement) to document all current processes and pathways used to communicate in a tsunami to enhance coordination and communication. Given that many of the fire stations within the Port Angeles and Sequim area may be staffed with volunteers, clearly outlined communications processes will only improve the effectiveness of actions taken along the waterfront area when a tsunami alert has been issued. This is especially prudent given that many waterfront entities, both owned by the Port or neighboring the Port, may need to share critical information regarding their actions upon receipt of notification of an impending tsunami. For example, the Coho Black Ball Ferry line highlighted that they would be in direct contact with their Port Captain to determine what actions to take dependent on the situation. Critical information would then be shared with the local emergency manager in Port Angeles.

Formally documenting these key communication steps would be advantageous for the Port, as procedures could then be tested and verified through exercises, improving coordination between Port staff and local first responders. This would also allow the Port to address how their communication channels and pathways may be altered in a local earthquake and tsunami, in which earthquake impacts may dramatically alter the operability of key communications pathways.

Remove or Secure Hazardous Materials Used or Owned by Port

Tsunamis become even more dangerous when their debris carries hazardous chemicals and materials. As tsunamis inundate port facilities, barrels of petroleum fuel, manufacturing chemicals, remains of paints, oils, and solvents, and other types of waste products can be spilled, dislodged, and spread out of containment. This compounds existing damage and debris cleanup by creating toxic conditions for port users and staff and has significant ecological consequences. The ability to move portable hazardous materials out of the tsunami inundation zone and/or the ability to secure their containment depends on the tsunami's wave arrival time. While there may be enough time to remove or secure hazardous material for distant source tsunamis, there may not be enough time to do so during most local source tsunamis.

Taking actions to secure HAZMAT storage sites is of the utmost importance to reduce the cascading impacts of an earthquake and tsunami, including extensive environmental cleanup and reducing the risk of flammable chemicals in waterways. The USCG maintains responsibility for the safety and security of navigable waterways in an emergency, with primary responsibilities in oil spill response. However, if tsunami inundation creates a significant spill along Washington's coastal waterways, the time required for a federal assessment and then resource acquisition may exceed 72 hours or more after the end of the tsunami threat. Incorporating oil spill response into local tsunami planning efforts will help reduce the likelihood of negative outcomes for local communities.

This action is feasible

The Port has two 12,000-gallon fuel tanks (one diesel, one gasoline) at each location. At the Port Angeles Boat Haven, these tanks are stored underground on a jetty. John Wayne Marina's tanks are stored about 100 feet from the shoreline, out of the inundation zone. While these tanks are privately owned, procedures have been developed for emergency shutdown, which is a quick process. On-site maintenance staff have the authority to shut off tanks and are staffed from 8:00 AM to 5:00 PM during normal business hours, with on-call staff available after hours. Additionally, the 24/7 security team undergoes annual training to ensure that they know how to shut off the fuel supply in an emergency. In both local and distant tsunami scenarios, shutting down port-owned fuel tanks is a quick action that can help protect property and prevent cascading impacts.

To further reduce the potential for hazardous materials impacts, the Port should work with Port tenants and Port staff to ensure that they have procedures in place to shut down and/or secure any exposed sources of hazardous materials, such as the boat maintenance facility. This can drastically reduce the impacts to Port-owned properties and better prime them for a faster recovery once the tsunami has ended.

Similarly, the Port should work with local emergency management and Washington Emergency Management Division to educate the liveaboards and other members of the boating community on the tsunami hazard and risks. This can help empower the boating community to take preparedness actions, including securing potential sources of hazardous materials on their vessels (fuel tanks, detergents, or other chemicals).

It should be noted that other facilities along the Port Angeles waterfront may become sources of hazardous materials release. Of greatest concern is the fuel depot located at the base of Ediz Hook, just north of the lagoon. The fuel depot currently has nearly 6 million gallons of fuel on the property. Adjacent to the fuel depot is the paper mill. Although no longer in full operation, the risk of chemical spill remains. This risk can potentially be addressed by a skeleton crew that still works at the facility, although exact details on their expected actions in tsunami response are unknown. Clallam County Emergency

Management should work with the fuel depot and paper mill owners to gain a better understanding of their tsunami response capabilities, plans, and procedures and share that information with the Port to provide a better understanding of the hazardous materials spill risk in a tsunami. Outside of the fuel depot, the U.S. Coast Guard Station/Air Station Port Angeles has developed procedures to shut down their fuel infrastructure in tsunami response.

Identify Boat Owners/Individuals Who Live Aboard Vessels and Establish Notification Processes

Communicating with boaters is essential during tsunamis, especially liveaboards. Notifications can run the gamut from simple alerts stating there is potential for damaging waves incoming to more lengthy communications that include instructions about protective action recommendations and other vital emergency information. It is important to remember those who live aboard their vessels may be reluctant to leave and/or want to return as soon as possible to check on their belongings. Since tsunami waves may persist for many hours and/or days, creating dangerous conditions that will restrict liveaboards from safely returning, they will be temporarily, or possibly permanently, displaced from their homes.

Having a contact list of boat owners, including liveaboards, improves alerting capability so they can be rapidly informed about and more quickly take protective actions during tsunamis. Notifications can be delivered many ways: through phone trees, email notifications, text messages, or even by personnel in the harbor using loudspeakers. It is worth noting that it can be challenging to account for all liveaboards due to housing instability and seasonal influxes of international fishermen. Remember, boaters may not be able to receive any one method of tsunami notification so the redundancy of multiple methods of notification is vital.

This action is feasible

The Port of Port Angeles will be notified of a tsunami threat via multiple pathways. Primary notification for distant-source tsunamis will be via Clallam County Emergency Management's Everbridge process. Upon receipt of the tsunami bulletin from Clallam County, the harbormasters will broadcast the bulletin via VHF radio, and the message is sent to all Port staff via Microsoft Teams. The U.S. Coast Guard will also push out tsunami alerts via VHF radio channel 16 as a Urgent Marine Information Broadcast (UMIB). To gather updates, the Executive Director and Emergency Operations Manager for the Port sit in on Clallam County Emergency Management-led conference calls to gather updated information about the expected tsunami and impacts to both the Port Angeles and Sequim Bay areas. This ensures that the Port will be able to share the latest information with their staff and customers.

If under a tsunami warning, the All Hazards Alert Broadcast (AHAB) tsunami siren network, operated and maintained by Washington Emergency Management Division, will be activated. This includes the siren right next to the Port Angeles Boat Haven on Marine Drive. Additionally, a tsunami warning will result in activation of the Wireless Emergency Alert

(WEA) and Emergency Alert System (EAS) methods, meaning that all available and connected cell phones, TVs, and radios will receive notification of the tsunami alert. One of the primary challenges with mass notifications in Port Angeles is due to the city's location. Many areas of Port Angeles, including the waterfront, receive cellular coverage from Canadian networks. This may impact the ability for residents to receive a tsunami alert and take timely action. Incorporating multiple alert dissemination pathways improves the reach of tsunami alerts.

A few dozen liveaboards reside at both the John Wayne Marina and Port Angeles Boat Haven. The Port has established processes for the 24/7 security team to contact the liveaboards by cell phone if under a tsunami alert, with a backup option to go boat-to-boat to reach all liveaboards within the respective marinas.

To reduce the burden of the notification process for the security team and overcome the challenge of inconsistent or lacking cellular coverage, the Port should work with local and county emergency management and Washington Emergency Management Division to educate the boating community and the public on the meanings of the tsunami alert levels, how they can receive alerts, and protective actions they can take upon receipt of a tsunami alert. Ensuring visibility of this information on the Port website, at informational kiosks, and via educational opportunities will cover not only existing residential populations, but also tourists who are unfamiliar with the area and the tsunami hazard.

Restrict Traffic Entering the Port by Land and Aid in Traffic Evacuation

During a tsunami, one of the main life safety actions is evacuation to high ground and/or vertical evacuation structures. To facilitate this, ports and marinas should develop a strategy to coordinate with local government officials to restrict vehicular and pedestrian traffic from entering port/marina-owned property in the inundation zone and assist in the safe and orderly evacuation from those areas. This will ensure the safety of vessel owners who may feel compelled to take their boat out to deeper water as a tsunami approaches, putting themselves and their vessel in unnecessary peril. Response actions that restrict entry include closing gates to port entrances and blocking roadways with barriers such as port/marina owned vehicles. Personnel can aid local government evacuation efforts by utilizing flags, hand gestures, and/or temporary signage to guide the public away from the inundation zone. If staff can assist in evacuation efforts, it is important to provide them with high visibility clothing or vests and flashlights to improve their safety and effectiveness.

This action is feasible

The Port does have available roadblock equipment to block off roads near Port areas for certain emergencies, although they have not developed procedures for how to utilize the equipment in tsunami response. In previous emergencies, including king tides and the 2022 Tonga tsunami advisory for Washington, the City Roads department has shut down Marine Drive, which connects the mainland to Ediz Hook. Ediz Hook is of particular concern as any members of the public on the Hook face the farthest distance to evacuate to high ground and the Hook will be completely inundated in a Cascadia Subduction Zone tsunami. In a distant tsunami, in which wave arrival may be several hours away, restricting access to Ediz Hook will be vital as the public tends to gravitate towards coastal areas to observe the tsunami despite the inherent risk.

For John Wayne Marina, the Port can simply close off the northern side of the parking lot as inundation is limited, even in a local CSZ tsunami. The Port of Port Angeles should work closely with the City of Port Angeles and Sequim to identify roles and responsibilities and priorities for closing down specific roads, such as Marine Drive. This can create opportunities to utilize the Port's roadblock equipment so that the cities can utilize their equipment in other city-owned locations in which access needs to be restricted and prioritize other life safety actions. This agreement can be finalized as part of a Memorandum of Understanding (MOU) to ensure procedures are clearly defined and improve continuity.

Pre-Stage Emergency Equipment Outside Affected Area

The aftermath of a destructive tsunami requires a significant number of emergency responders and their equipment to show up at the affected area to begin search and rescue, salvage, and clean up. If any emergency response equipment normally resides within the inundation zone, it should be pre-staged out of the area before the waves arrive, so it is not damaged and remains operable for the post-incident response. Any necessary equipment should be identified in advance and a plan made to determine what equipment needs to be pre-staged outside of the tsunami inundation zone before the first tsunami waves arrive. This could save time, resources, and staffing for response during a tsunami where resources may already be limited.

This action is feasible

Currently, the Port plans to move their heavy machinery along the Port Angeles waterfront to the nearby, Port-owned William R. Fairchild Airport in a local CSZ tsunami. This process relies on the 5 - 8 internal personnel with CDL class licenses to operate the machinery to move it out of the inundation zone. The primary challenge with this process will be to ensure the safety of residents and staff who are evacuating on foot, as the City has unofficially designated an assembly area at Hamilton Elementary School. Depending on the route taken by the heavy machinery operators, in combination with residents and tourists who may be evacuating, there is potential overlap between the chosen routes. This challenge can be alleviated through clearly defined procedures that are practiced on a regular basis to ensure that the routes are clearly understood by Port staff and the public is aware of the machinery traffic along the evacuation routes. The Port should consider creating a permanent home at the airport facilities for any heavy machinery that is not in operation day-to-day. This can add additional capacity for other critical tsunami response actions and reduce the risks associated with evacuating machinery under stressful, time-bound response circumstances.

The William R. Fairchild Airport is a critical asset that the Port can use for staging additional response and recovery assets and equipment as well. The Port is currently working on a formalized agreement to grant the USCG Station Port Angeles permission to utilize existing facilities at the Fairchild Airport as a staging area for their operational helicopters. This agreement will be beneficial for tsunami response for several important reasons. First, it allows the USCG to maintain the operational readiness of their aerial assets for tsunami response. Given the location of the USCG Station on Ediz Hook, the entire station will be inundated approximately an hour after the start of a local CSZ earthquake. If USCG assets were to remain on Ediz Hook, they would be severely damaged and rendered inoperable, which would be a major loss in capability for the USCG response. Second, this agreement would solve the current issue of utilizing Port Angeles High School as the USCG staging area. Discussed in the "Activate Incident Command at Evacuation Sites", the City has currently designated Port Angeles High School as the primary assembly area. The USCG has also chosen this location as a staging area. Moving the USCG staging area to Fairchild Airport alleviates the challenges of bringing the public and USCG assets to the same location. While the USCG primarily intends to move their aerial assets to Fairchild Airport, the Port should discuss the possibility of utilizing available space for pre-staging USCG maritime response assets and equipment to expand the capabilities of tsunami response personnel.

While the William R. Fairchild Airport has and will continue to play a valuable role in pre-staging emergency equipment, the Port should be cognizant of its vast geographical area when it comes to emergency planning. The John Wayne Marina is approximately a 40-minute drive from Fairchild Airport, and the Port has additional properties throughout Clallam County, including Sekiu Airport. Incorporating these geographical challenges for local and distant tsunami planning will ensure that the Port is aligned to effectively respond to any tsunami, regardless of the source. Fairchild Airport's participation in the 2016 Cascadia Rising national-level exercise and the WA National Guard's 2017 Domestic Operations Command Post training exercise shows the Port's continued commitment to improving local and regional disaster response efforts.

Pre-Identify Personnel to Assist in Rescue, Survey and Salvage Efforts

A major part of post-tsunami response is rescue, survey, and salvage operations. Once the tsunami threat has subsided and the inundation zone is safe to reenter, first responders will need to conduct search and rescue as there may be survivors trapped under debris or even pulled out to sea. Port personnel will need to conduct survey safety assessments to determine what port facilities are not safe to enter and use. Port entrances, shipping lanes, and navigation channels will also need to be assessed to determine if they are safe for vessel reentry due to potential risk from debris, scouring, and movement of sediment. Finally, personnel will need to determine what facilities or equipment can be salvaged and whatever is not salvageable will need to be removed.

This action is feasible

Once the City of Port Angeles Police Department issues the all-clear notice for the public to return to impacted areas, the Port will be able to return to their facilities in the post-tsunami environment to begin rescue, survey, and salvage operations. Infrastructure and facilities will be assessed for damage by the Marine Terminal Manager and the Port's Facilities Manager to identify the status of systems that are required for normal operation.

The USCG will be a critical partner for the Port to coordinate with throughout the reopening process, especially for a local CSZ tsunami in which catastrophic impacts are expected across Washington. The USCG is responsible for the safety and navigability of the Marine Transportation System, which includes the Strait of Juan de Fuca and Port Angeles and Sequim Bay waterways. They have the authority and responsibility to immediately begin search and rescue operations without the need to wait for a state or federal disaster declaration.

Although the USCG will make efforts to evacuate maritime vessels to deep water and trailer assets to the nearby William R. Fairchild Airport, it is quite possible that they will lose some assets (both marine and air) in either tsunami scenario discussed in this strategy. While that may impact their initial response capacity, the USCG highlighted that they would be scattering resources across the impacted areas of the coast. Upon approval of a disaster declaration, additional resources would be available, including Urban Search and Rescue (USAR) support via National Strike Force Resources from California.

USCG Northwest District personnel also outlined their roles and responsibilities for the damage assessment and re-opening process for Washington's ports. Once the Port facilities have been evaluated for damage by both Port staff and the Marine Transportation Recovery Unit (MTRU), tenants would be notified of any damage. The MTRU coordinates response with state and local jurisdictions and other key partners. Before determining the operability of a port and reopening or restricting access to a specific port, the USCG would track and document all Aids to Navigation (ATON). Once the port is cleared for operations, the USCG would start vessel queueing and staging in coordination with Vessel Traffic Services (VTS) in Washington and Canada. Throughout the process of vessels returning to impacted areas, the USCG will coordinate and gather Essential Elements of Information (EEIs) from private entities such as the Coho Black Ball Ferry. As needed, the U.S. Army Corps of Engineers (USACE) would be brought in to assist with damage assessments for infrastructure and facilities. The response and recovery process heavily depends on the USCG and the MTRU. Entities including the Coho Black Ball Ferry would need to coordinate with the USCG and customs and border agencies in both the U.S. and Canada to resume normal operations.

Additionally, the USCG is a primary agency to manage oil spill response. A tremendous barrier to search and rescue, survey, and salvage operations will come from the Marathon Fuels Tank Farm located on the base of the Ediz Hook. Marathon has shared that they expect fuels to spill out into the waterways in the Cascadia Subduction Zone tsunami scenario due to the extreme forces from the approximately 20 feet of expected inundation. While the exact level of leakage cannot be predicted, there are nearly six million pounds of fuel currently being stored at the tank farms. The more fuel that spills, the longer and more expensive the required cleanup will be, which may also impact local responders' ability to conduct other operations.

Another key entity for damage assessments, distribution of emergency supplies, and movement of minorly injured (non-life threatening) victims is the Disaster Air Relief Team (DART). The DART is comprised entirely of volunteers with the intended purpose of aiding communities when regional surface transportation is disrupted. For this reason, the DART plan is likely to be activated in a local CSZ event in which roadways and bridges may be heavily damaged or destroyed. The plan may or may not be activated for a distant tsunami. The DART plan, owned and updated by Clallam County Emergency Management (CCEM), outlines the roles, responsibilities, and operations of the DART with job aids and other helpful resources for the team. In tsunami rescue, survey, and salvage, the DART can provide rapid damage assessment and situational awareness to Clallam County Emergency Management for the entirety of Clallam County's coastline. Additionally, the DART can transfer supplies to other locations in the county (Sekiu and Quileute Airports) and handle basic medical transport as needed. The DART operates out of William R. Fairchild Airport, where their aircraft and operations center is located. This can ensure that difficult-to-reach places within Clallam County can access to supplies much earlier than any federal response would be able to arrive. One critical consideration for the activation of the DART plan and coordination with DART is that Clallam County Emergency Management's Emergency Operations Center (EOC) is currently located in the basement of the Clallam County Courthouse building on Lincoln and 4th Streets in Port Angeles. According to Washington Geological Survey data, the building sits adjacent to a historical landslide area and is within a low to moderate risk zone for soil liquefaction from earthquake shaking (https://dnr.wa.gov/washington-geological-survey/publications-and-data/geologic-information-portal). Historical photos provided by CCEM show that the courthouse was built on the edge of a ridge, with adjacent Lincoln Street built on areas of fill with wooden supports (see Figure 55), which may exacerbate the risk of sliding or ground deformation and impact the functionality of the EOC in a local CSZ earthquake and tsunami. Fortunately, CCEM is working to move their EOC to a lower risk area adjacent to William R Fairchild Airport which will improve their capabilities in local earthquake and tsunami response.

Figure 55. A historic photo of Clallam County's courthouse, with construction on wooden supports that has since been filled. (Clallam County Emergency Management)

The entire process outlined above will require extensive coordination between the USCG, WA EMD, city and Clallam County emergency management, the Port, and Port tenant organizations to effectively and efficiently move towards a state of normal operations. The Port should continue to discuss their roles and responsibilities in rescue, survey, and salvage efforts with the agencies listed above to accurately document the reopening process as part of a Business Continuity Plan (BCP). BCPs outline the critical steps required to quickly return a business to an operational state after experiencing a threat, disaster, or other event that disrupts normal operations. While BCPs typically cover all hazards, one study on tsunami resistance for Keelung Port in Taiwan identified BCP promotion as the core of the "golden triangle" of tsunami resistance efforts, with reinforcing critical infrastructure, strengthening early warnings for evacuation and information communication, and enhancing disaster relief and rescue performance the key aspects in which a BCP is intrinsic to. Working to identify the key roles, responsibilities, processes, and procedures in the post-tsunami realm are critical to ensure an effective and efficient recovery for the port and its tenants. The Port should continue to build off the information discussed during the response workshop and coordinate with the Coast Guard, Clallam County Emergency Management, Washington Emergency Management Division, and the port tenants to further define and outline the process to return the Port to normal operations after the next tsunami.

Secure Moorings of Port Owned Vessels

If vessels are properly and securely moored during a tsunami, there is a higher chance they will withstand the fluctuating currents and not become dislodged. Prior to the initial wave arrival, boat owners and harbor personnel can visually check that vessels are securely moored. Given the size of some harbors and number of slips and vessels, it is not possible to check the entire area before wave arrival. Given this limitation, the check should begin in the areas identified as most at risk of strong currents and other hazardous conditions. Vessel captains and owners should be encouraged to securely moor their vessels every time they dock, allowing a visual check to be conducted quickly. If owners and captains are vigilant about their mooring lines and security, then very few vessels should need to be additionally secured.

This action is feasible

The Port has several vessels that are either docked at one of their properties or in operation as part of day-to-day tasks. Securing moorings is an action taken by Port staff as part of their daily operations. Incorporating proper mooring techniques as part of education efforts and connecting them to the tsunami hazard can be an effective approach for helping liveaboards and those visiting the Marina understand how to best protect their vessels. The Port can work with Washington Emergency Management Division to provide tsunami response recommendations and other protective actions via the Washington Tsunami Boater's Guide.

Evacuate Public/Vehicles from Waterfront Areas

Limiting the number of people and vehicles in the inundation area before dangerous tsunami waves arrive helps limit the amount of damage, debris, and casualties associated with the incoming waves. The fewer people and vehicles in/around the inundation zone, the lower the overall risk and danger to life safety. Developing a detailed evacuation plan for these dangerous areas is the first step to ensuring a comprehensive evacuation of people and vehicles from the area during a tsunami.

This action needs review

Successful evacuation from the Port of Port Angeles facilities and waterfront areas requires extensive coordination with the U.S. Coast Guard, terminal tenants, City of Port Angeles emergency management and first responders, Clallam County Emergency Management, Roads or Public Works Departments at the city and county level, and internal personnel at the Port. This is due to the extensive area of the Port Angeles waterfront including the Ediz Hook. Those with the furthest distant to evacuate are the USCG Station/Air Station Port Angeles and any members of the public at Harborview Park or any other publicly accessible recreation areas along Ediz Hook Road. From the base of the hook east to the Red Lion hotel are a variety of port property (including all seven terminals) and local commercial buildings, including the Front Street and First Street areas which are home to a variety of restaurants and businesses such as the Port Angeles Wharf and Marine Life Center. Also of great concern is Terminal 2, home to the Coho Black Ball Ferry, a 1,000 passenger, 115 vehicle capacity ferry that takes numerous trips daily between Port Angeles and the city of Victoria, British Columbia, Canada.

To ensure safe evacuation for residents and visitors alike, coordination that considers the varying populations and their challenges is vital for life safety, particularly in a local CSZ earthquake and tsunami. Clearly defining roles and responsibilities that outline primary and support agencies for key actions can enhance response efforts by reducing confusion and allowing responders to focus their time and energy on planned, specific actions.

Specific planning considerations for tsunami evacuation for the Port to address include assisting liveaboard communities at both the Port Angeles Boat Haven and John Wayne marinas, evacuating personnel from terminal facilities, and assisting in evacuation for the Coho Black Ball Ferry, a tenant at terminal 2 at the Port. Evacuation is especially prudent for a local Cascadia Subduction Zone (CSZ) earthquake-generated tsunami as inundating waves arrive along the Port Angeles waterfront around 50 minutes to an hour after the start of the earthquake. If the Coho Black Ball Ferry is docked at the Port Angeles terminal or very near-shore to Port Angeles along its route, the best course of action would be to dock and unload onboard vehicles and passengers – a process that takes around 10 – 15 minutes once successfully docked under normal conditions. An additional layer of complexity for ferry evacuation is the presence of Canadian nationals. In normal circumstances, all passengers are required to go through the Customs process once unloaded from the ferry. Due to the high impact and short response time before waves arrive from a local CSZ tsunami, emphasis for passengers should be evacuating them to high ground immediately once unloaded. While the Coho Black Ball Ferry has stated that they currently do not have any plans to request assistance from the Port or the City for additional evacuation resources, the Port and City should work with the Ferry, U.S. Customs and Border Protection, and Canada's Border Services Agency to identify an effective path forward for rapid evacuation off of the ferry.

A major gap in tsunami evacuation for the Port Angeles area is a lack of assembly areas – designated areas in which evacuated members of the public can gather for the duration of a tsunami threat. The City's plans only designate one assembly area at Port Angeles High School. Additionally, a tsunami walk map completed by the Washington Geological Survey outlines seven additional assembly areas: Bo Baggins Daycare Center, the Safeway parking lot at 3rd and Laurel, the Playground at 5th and Oak, the Vern Burton Community Center, the Port Angeles Senior Center, Jefferson Elementary School, and Hamilton Elementary School.

While all of these identified sites have the potential to be used as assembly areas, clearly identifying a small group of these assembly areas for both the downtown and western areas of Port Angeles that align with proposed tsunami evacuation routes is the best path forward. The Port should work with local emergency management and first responders to ensure that evacuation messaging and education to the public is aligned.

Another critical consideration for the port is to verify the USCG's evacuation plans in a local CSZ tsunami. Due to the criticality of UCSG vessels in tsunami response, the USCG Station Port Angeles highlighted that they are likely to take their docked vessels out to deeper water to protect them from the tsunami impacts. This evacuation would be supported by the Puget Sound Pilots, who have a station on Ediz Hook and the ability to carry an additional 10 people per vessel on their vessels. However, not all critical assets may be operationally ready and may be pulled out of the water for maintenance or storage. If needed, the USCG Station Port Angeles highlighted that they intend to trailer vessels to transport them to higher ground. As discussed in the "Pre-stage emergency assets outside of the inundation zone section", the port intends to move heavy machinery to high ground in a local CSZ tsunami. The potential for pedestrian evacuation from public recreation spaces on Ediz Hook, USCG trailered assets from Station Port Angeles, and any heavy machinery owned by the port evacuating from the western side of the Port Angeles waterfront creates additional safety concerns for evacuation. Ensuring that the Port is able to coordinate and communicate with USCG and City personnel can organize these efforts and alleviate some of the safety concerns. This scenario can also be simulated as part of a larger evacuation drill along the Port Angeles waterfront to reduce confusion and ensure the safety of all those evacuating. This could be made even more realistic during the Great Washington ShakeOut, a statewide earthquake and tsunami evacuation drill, as the tsunami siren on Marine Drive would be activated.

Activate Incident Command at Evacuation Sites

During and after a tsunami, evacuation sites will likely be crowded with evacuees. People may be injured, scared, and looking to Port staff for answers and explanations. Activating an Incident Command at the evacuation area(s) can help to provide clear and direct leadership, establish chain of command, and ensure span of control. It is important to have qualified authorities who understand the Incident Command System (ICS) and how it operates filling positions of leadership. Having an organized and structured command at these locations can help reduce confusion, organize and calm evacuees, and prepare for response activities after the tsunami.

This action needs review

Currently, the City of Port Angeles had documented that the Port Angeles High School is an identified assembly area for the public to use; however, the USCG also plans to bring several of their assets out of the inundation zone on Ediz Hook and utilize the school as a temporary staging site. The Port is currently working to formalize agreements with the USCG (see Mutual Aid section) to utilize the William R. Fairchild Airport as a replacement site for the high school, which will alleviate this issue.

The Washington Geological Survey worked with local planning officials to create a tsunami evacuation walk time map for the City of Port Angeles (see Figure 56 below). This map

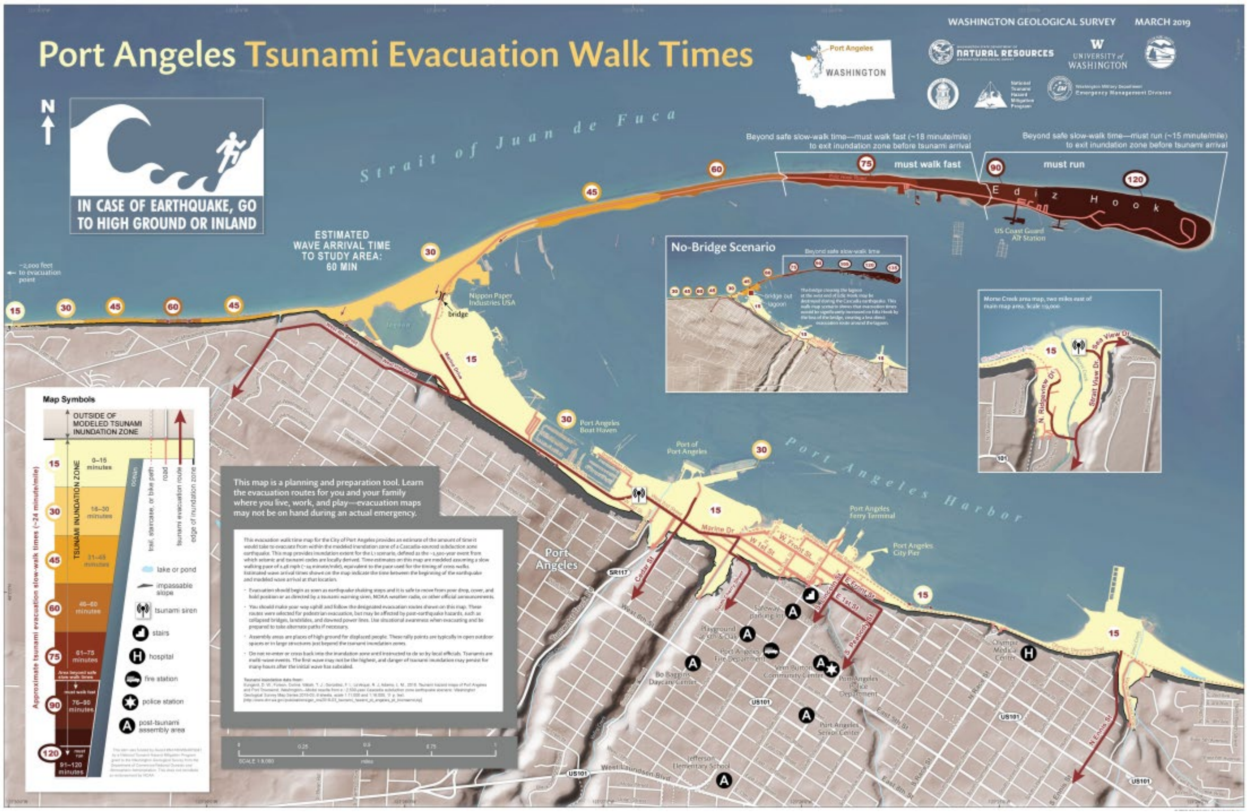


Figure 56. A Tsunami Evacuation Walk Time map developed by Washington's Department of Natural Resources. The darker brown colors represent longer evacuation times (90 or 120 minutes) once earthquake shaking has stopped, while the lighter orange and yellow colors (30 or 15 minutes, respectively) represent shorter evacuation times. Red arrows show tsunami evacuation routes. (WA DNR, 2019)

identifies evacuation routes and several potential post-tsunami assembly areas for the public to gather. These sites include Jefferson Elementary School, the Port Angeles Senior Center, Bo Baggins Daycare Center, the playground at 5th and Oak, the Safeway parking lot at 3rd and Lincoln, Vern Burton Community Center, and Hamilton Elementary School. Establishing incident command at all of these potential sites to provide organization and structure will be tremendously helpful for the community, especially when many tourists and Canadian residents may be visiting the area.

Due to the limited capacity of local first responders, the City should work with the Port and local school districts to identify a smaller set of assembly areas closer from the identified list above with clearly marked signage identifying each site as an official assembly area. This would verify that the local first responders are able to effectively staff and manage these sites more efficiently, while maximizing resources for other response actions. The Port and City can incorporate these official assembly sites as part of their ongoing tsunami evacuation and education efforts and then share this information widely for saturation and understanding amongst the community members.

Activate Mutual Aid System as Necessary

Activation of a Mutual Aid System can help locations experiencing an emergency receive additional assistance from nearby jurisdictions that are not part of the emergency or are less impacted by it. Activating this type of system allows authorities in an area struck by a disaster access to additional resources that may be scarce during the initial response or may be needed in numbers that exceed the amount available in the disaster area. For ports or marinas, this could be as simple as establishing a Memorandum of Understanding (MOU) with a nearby city or county emergency management to access resources that are outside of their capabilities, such as heavy machinery for debris removal or additional personnel to support damage assessments.

This action needs review

The Port is currently working to identify and address gaps in their mutual aid system. An ongoing mutual aid project discussed further in the "pre-staging emergency equipment outside affected area" action is developing a Memorandum of Understanding with the USCG Station/Air Station Port Angeles to utilize the William R. Fairchild Airport facilities as a staging area for USCG assets to ensure they are operable for tsunami response once the threat has subsided. The Port has recognized that agreements such as this need to be formalized and should take steps to document and verify the information with key response partners, including the USCG, local emergency management and first responders, and Clallam County Emergency Management. Formalizing these agreements will provide the opportunity to further refine them through exercises, ensure their continuity and longevity, and maintain successful coordination in both distant and local tsunami incidents.

At the county level, Clallam County owns the Disaster Air Relief Team plan. The plan is activated in emergencies in which regional surface transportation is disrupted. This means that the plan will very likely be activated in a local CSZ earthquake and tsunami due to major damage to transportation infrastructure from the earthquake shaking alone. For the distant Alaska tsunami scenario, the plan may or may not be activated depending on the impact of the tsunami itself. The Disaster Air Relief Team is a volunteer-based community aid group that may transfer supplies, assist in survey and damage assessments (as described below), and can handle basic medical transport.

Reposition Ships Within the Port

Using tsunami current velocity maps, ports and marinas can identify areas that are most likely to encounter strong currents during tsunamis. Once identified, they can then determine if moving ships out of those areas of danger and placing them in locations less likely to experience strong currents would be beneficial. Which ships would need to be moved and to where is something that should be determined well ahead of a tsunami and detailed in a written plan. Ideally the Port would focus on large ships with deep keels in dangerous areas that may be more likely to experience sufficient drag to rip them free of moorings, thereby damaging infrastructure and leaving the ships free-floating to act as major debris. There would need to be clearly established SOPs developed for this response which detail specific instructions as to who determines that a vessel should be moved; that there is enough time to safely move the vessel; and ultimately who is responsible for moving the vessel. These SOPs would need to be reviewed, tested, and updated on a regular basis to ensure an effective response during a tsunami incident.

This action is not feasible

The John Wayne Marina has a natural land formation that juts out into Sequim Bay north of the entrance to the Marina. This land formation protects the Marina from increased current speeds in either tsunami scenario, with the breakwater offering additional protection from inundating waves in the distant Alaska tsunami scenario. Attempting to reposition ships within the breakwater or moving them further south into Sequim Bay is not advised as the Marina area is the safest refuge for vessels. However, the Port could consider moving any vessels docked at the Pacific Northwest National Laboratory (PNNL) into John Wayne Marina. Adequate planning would be required to ensure that PNNL has the capacity to move the vessel and the vessel has a clearly identified space to dock for the duration of the tsunami itself. After, it would need to be verified that the PNNL dock is safe to return to, given its location just west of the Travis Spit where it is exposed to increased current speeds and inundating waves.

On the Port Angeles side, larger commercial vessels, barges, and the Coho Black Ball ferry may be docked at terminals or in the open water at any given time. Additionally, the Port Angeles Boat Haven, Port Angeles Yacht Club, and Knot Impossible Sailing Group pack the Marina between terminals 3 and 7. Given the impacts of both the local CSZ and distant Alaska tsunami scenarios, Port staff capacity and time are better spent on other response actions. With nearby vessels either heading to deeper water in the Strait of Juan de Fuca or to the closest open dock, trying to reposition larger vessels brings additional navigational challenges in the Port Angeles Harbor area. Given that large ship movements may need to be led by the Puget Sound Pilots, who have a station on Ediz Hook, this further complicates this response action.

For members of the public whose vessels are already tied up, the best action to take is to follow their evacuation route inland to high ground.

Remove Small Vessels from the Water

Tsunamis can generate an extensive amount of debris which can damage vessels and other maritime assets. Prior to tsunami wave arrival, ports and marinas may be able to remove some assets and smaller vessels from the water and encourage their users to do the same. This could reduce the potential for these vessels and assets to be damaged by debris or become drifting debris themselves. However, the ability to remove vessels and assets from the water is dependent on the tsunami's estimated wave arrival time. While there may be enough time to execute this process for distant source tsunamis, there may not be enough time to do so during most local source tsunamis.

Removal is also a time-consuming and labor-intensive process which requires adequately trained personnel and may require specialized equipment such as shoreside boat lifts and trailered vehicles to remove vessels from the water. To effectively coordinate this process, proper training and exercise is needed for port staff and users need to be informed of these processes and recommendations. If a port or marina owns vessels essential to life safety, such as equipment used for search and rescue operations, fire and spill response, and law enforcement activities, they should be prioritized for removal from the water.

This action is not feasible

The Port has a variety of vessels that they use in their day-to-day operations. For removing small vessels from the water, the Port has an 80-ton travel lift currently at the Port Angeles Boat Haven, in which the Port docks the majority of their vessels. Some of the Port tenants have a 300-ton travel lift for removing larger vessels from the water. However, while the equipment required to remove vessels from the water is available, this action is not feasible for the tsunami scenarios evaluated as part of this strategy. For the local CSZ tsunami scenario, there is not enough time to prioritize vessel removal from the water, as water drawdown starts around 25 minutes after the start of the earthquake, with the first inundating wave arriving around the 50-minute mark. Initial actions should prioritize life safety and ensure that all personnel have safely evacuated on foot to high ground. For the distant Alaska tsunami scenario, the Port has chosen to prioritize other response actions given the limited inundation and 5 – 8 knot current speeds modeled for this scenario.

Given the approximate 4-hour time window before waves would arrive from a distant Alaska tsunami, the Port could consider working with their tenants to create agreements to use the tenant-owned and Port-owned boat lifts to remove critical assets from the water. The primary concern with the distant Alaska scenario comes from the 5 – 8 knot current speeds, which can cause moderate to severe damage to the aging maritime infrastructure within the Port Angeles Boat Haven. Utilizing the boat lifts could further reduce the risk of damage to any key assets, particularly those that are critical for response or recovery activities.

Remove Buoyant Assets Out of and Away from the Water

Buoyant assets such as floats, buoys, empty drums, barrels, and other manufacturing or fishing supplies can become debris during tsunamis. For this reason, any items that will easily float and are not needed near the water for normal operations should be moved to an area outside of the inundation zone when possible. Similar assets that need to remain in the inundation area should be properly secured. While a large local source tsunami is likely to dislodge and damage even well secured buoyant assets, they may remain secured during a smaller distant source tsunami.

This action is not feasible

The biggest concern within the study area for buoyant assets is the Port-owned 25-acre log yard just west of the Port Angeles Boat Haven. Log and lumber loading is one of the primary full-service operations at the Port. Logs are typically on-site year-round and are likely either on land in large stacks or in the water on the west side of the harbor. In Crescent City, California during the tsunami caused by the 1964 Great Alaska earthquake, logs and lumber from three lumber yards caused a significant amount of damage by colliding with buildings, cars, and other objects. Additionally, all of the lumber that was picked up found a resting place elsewhere in the city or floated off, creating significant challenges in the cleanup and recovery phase for the city. Currently, the Port does not secure their log piles at the log yard in Port Angeles. The stacks of logs are kept in place for effective loading of barges. The Port should evaluate the need for mechanisms to secure log piles that are strong enough to withstand the rapid water-level changes and currents of inundating tsunami waves.

Outside of the log yard, the port did not identify any other significant buoyant assets along the waterfronts of Port Angeles or Sequim Bay. Given the level of effort and coordination to move all of the log piles from the log yard to another location, this action item is not feasible for either tsunami scenario evaluated.

Restrict Boats from Moving and Prevent Ships from Entering the Port During a Tsunami

Due to the strong, unpredictable currents and massive amounts of debris in the water during a tsunami, vessels in motion on the water can be in extreme danger. Eliminating or severely restricting vessels from being occupied and in motion on the water during a tsunami reduces the danger to life safety and can help limit casualties. Since the narrow entrances of most harbors are where tsunami-caused currents can be strongest, vessels should not enter or leave the harbor during a tsunami. While boaters out on the water should be encouraged to return to the harbor if possible before tsunami waves arrive, entering the harbor should not be attempted once the initial wave crest or trough has arrived. These locations will be highly dangerous to navigate during a tsunami and, when currents are at their strongest, may prove impossible to pass through at all.

This action is not feasible

The Port does not have the authority to prevent ships from entering or leaving either of the marinas. The US Coast Guard can restrict the entrance of recreational traffic into or out of the Harbor, which they do for hazardous bar conditions. The Captain of the Port has the responsibility to issue alerts to mariners. These alerts are sent out via VHF radio channel 16 as either an Urgent (tsunami warning) or Safety (tsunami advisory or watch) Marine Informational Broadcast to notify boaters of the impending tsunami. Any port closures or restrictions can be included as part of the content of that message. The COTP could restrict movement of vessels within the Port of Port Angeles, although they may not have the resources to enforce this directive.

The Port should work with the Washington Emergency Management Division and City and County emergency management on a series of outreach initiatives and education opportunities to inform boaters of protective actions to take during tsunamis and different ways to receive tsunami alerts when on land and on the water.

Section 5: Tsunami Mitigation Guidance

Mitigation actions represent a proactive and strategic approach aimed at reducing the potential risks posed by natural disasters before they occur. These interventions are vital in safeguarding both lives and property, necessitating a substantial investment of time, resources, and expertise. For tsunamis, the critical role of mitigation actions becomes evident in their potential to significantly reduce the impact on maritime infrastructure.

Below is a list of various potential tsunami mitigation actions for the maritime community that have been implemented in other states, offering insights into their practicality, implementation, and impact. These mitigation actions can be categorized into three primary buckets: soft mitigation actions such as installing tsunami signage and education, dock infrastructure upgrades, and larger infrastructure projects. Each description is crafted to empower communities and key decision-makers with a comprehensive understanding of the diverse measures available for minimizing the impact of tsunamis and fortifying maritime infrastructure against potential risks. By delving into the specifics of each mitigation action, this section fosters informed decision-making and proactive planning to enhance resilience in the face of potential tsunami events.

Tsunami Mitigation Actions

In the comprehensive evaluation of tsunami mitigation actions for the Port of Port Angeles, each potential action was evaluated based on its feasibility, classifying them as either 'Feasible', 'Needs Review', 'Not Feasible', or 'Complete'. This critical analysis considers the unique characteristics and vulnerabilities for the Port Angeles Harbor and John Wayne Marina areas. The applicability of these response actions extends to scenarios involving both an Alaska Aleutian Subduction Zone (AASZ) and a Cascadia Subduction Zone (CSZ) earthquake-generated tsunami.

The 'Feasible' designation implies that the mitigation action is deemed practical and implementable within the context of the local geography, infrastructure, and resources. Actions categorized as 'Needs Review' may require further scrutiny and adaptation to address specific considerations unique to the Port Angeles Harbor and Sequim Bay areas. Conversely, mitigation actions labeled as 'Not Feasible' may be challenging to execute or may pose inherent risks that outweigh their potential benefits in the context of life safety and protecting property. Actions labeled as 'Complete' describes actions in which the port has already invested time and resources, and further investment would not bring additional benefits from a risk reduction standpoint. This approach creates a targeted and customized approach to tsunami preparedness and mitigation for the Port Angeles Harbor and John Wayne Marina in the face of potential seismic events from both AASZ and CSZ.

Each mitigation action in the following section is structured as follows: background on the action, feasibility determination, and detailed reasoning gathered from conversations at workshops and check-in meetings. A summary of the feasibility of various response actions is provided in Table 4 below.

Tsunami Mitigation Actions	Feasibility for the Port of Port Angeles
Strengthen Cleats and Single Point Moorings	Complete
Improve Floatation Portions of Docks	Complete
Increase Flexibility of Interconnected Docks and Dock Fingers	Complete
Install Tsunami Signs	Feasible
Increase Size and Stability of Dock Piles/Increase Height of Piles to Prevent Overtopping	Feasible
Reduce Exposure of Petroleum/Chemical Facilities and Storage	Feasible
Improve Movement of Dock Along Piles	Feasible
Acquire Equipment/Assets to Assist Response Activities	Feasible
Install Debris Deflection Booms to Protect Docks	Needs Review
Widen Size of Harbor Entrance to Prevent Jetting	Needs Review
Construct Floodgates	Needs Review
Move Docks and Assets Away from High Hazard Areas	Not Feasible
Fortify and Armor Breakwaters	Not Feasible
Construct Breakwaters Farther Away from the Port	Not Feasible
Deepen or Dredge Channels Near High Hazard Areas	Not Feasible

Table 4. A summary of the evaluation of 15 actions for the Port of Port Angeles to consider to mitigate tsunami impacts. Each action was assigned a feasibility category based on documents and expertise provided by key Port of Port Angeles staff and their partners.

Strengthen Cleats and Single Point Moorings

The cleats and mooring points used to anchor vessels to docks need to withstand extreme forces during a tsunami. Vessels that are pulled free from their moorings during a tsunami quickly become part of the debris moving in the water, potentially destroying other vessels and infrastructure. Cleats and mooring points that are poorly installed or are of insufficient size for the vessels moored to them will not be able to withstand the forces exerted on them during a tsunami and could be ripped free (Figure 57). Lag bolts attaching cleats can snap or be pulled free from the dock structure; worn and rusty cleats can break off or bend, releasing lines.

To ensure that the mooring points remain secure even in extreme scenarios, cleats need to be rated strong enough to hold not just the weight of the vessels they secure, but also withstand the additional forces from the drag on those vessels due to the extreme currents of a tsunami. Such cleats and moorings should be secured to the dock structure with high tensile bolts and a backing plate so pulling forces are spread over a larger surface area.

Figure 57: Broken cleat in Neah Bay along Dock A (WA EMD)

This action is complete

No cleats were identified as needing to be replaced. The Port's current design incorporates cleat sizes that increase with size as the slip size increases. In other words, bigger ships have bigger cleats to better secure vessels to the dock infrastructure. The primary opportunity to ensure that vessels are adequately secured to docks can be evaluated as part of the refloat projects for the Port Angeles Boat Haven and John Wayne Marina, as vessel sizes have shifted away from the small 20-foot vessels to 25- or 30-foot vessels. If any cleats begin to wear down unexpectedly, the Port should remove and replace the cleats within a reasonable timeframe.

Improve Floatation Portions of Docks

The rapid onset of tsunami waves can over-top docks, causing them to sink and break apart if the docks are not sufficiently buoyant. It may appear that all docks have sufficient floatation portions under them if they are floating and rise and fall with the tides and waves. However, certain styles and materials of floating dock structures are in fact much more buoyant than others. Many docks are 'pontoon' style, where tubes of buoyant materials (sometimes filled with foam) run in a parallel track with a platform built on top. Another common dock construction technique is to use solid floating 'blocks' either at the ends of the dock structure or at widely spaced distances along the entire length (Figure 58). These styles, while common, will not prove as buoyant as docks with a floatation section that spans the entire underside of the dock area.

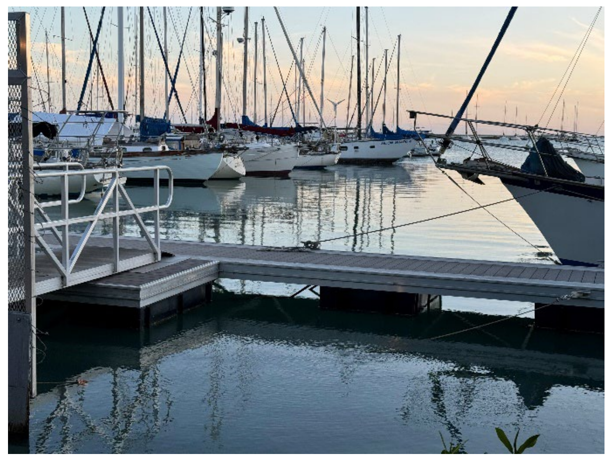


Figure 58: Docks built on floating blocks in Honolulu, Hawaii (WA EMD)

The most buoyant docks are built on top of sturdy, sealed 'blocks' made from High Density Polyethylene (a strong, impact resistant plastic) filled with buoyant foam such as Expanded Polystyrene (like Styrofoam) which spans the entire dock width and length. The increased buoyancy of full floatation docks will do best at handling the extremely fast changes in water depths that accompany tsunami waves.

This action is complete

The current design in use for the floats at both the Port Angeles Boat Haven and the John Wayne Marina incorporate best practices for tsunami-resistant float design. The polystyrene inner cores are encased in sturdy plastic coatings and extend the whole length of the docks. Water pipes hang off the side into the water to prevent freezing, with utilities down the center of each dock. The main pieces of the dock floats are primarily concrete.

As previously discussed in other sections describing dock infrastructure upgrades, the Port is planning to refloat portions of the Port Angeles Boat Haven in a few years, with the John Wayne Marina due for a refloat another five to six years after that. Due to a change in state regulations, dock floats are now required to be constructed for maximum light penetration. With the upcoming float replacements currently in the master planning phase, the Port should incorporate an updated design that meets the updated regulations and maintains the best practices used in their current design to reduce the impacts of a tsunami.

Increase Flexibility of Interconnected Docks and Dock Fingers

Figure 59: Broken docks in Crescent City, CA from the 2006 Kuril earthquake (USGS 2006).

The rapidly changing water levels, extreme waves, and unpredictable currents associated with tsunamis will test the flexibility of any dock system, including dock fingers. This can also be true for large storm surges and swells, bending or breaking them at joints connecting dock sections, as in Figure 59, and where dock fingers are attached.

The refracting waves of a tsunami move docks in both horizontal and vertical directions in ways docks may not have been subjected to prior to the event. Increasing the amount of movement between sections of docks at their joining points can help ensure docks remain connected and intact after tsunami waves recede. Increasing flexibility along the joints of dock sections and their fingers can involve lengthening gaps between the sections to allow for increased movement or utilizing more flexible types of hardware to make the attachments resistant to stress and fracturing.

This action is complete

Under the current design for the floats at both the Port Angeles Boat Haven and the John Wayne Marina, docks are connected by a series of walers with galvanized steel through rods that tie floating sections together. Steel construction utilizes one of the strongest and most malleable metals for dock construction, allowing for flexible movement under rapid water level changes in a tsunami. *Pile Buck Magazine* reports that “no other connection method, such as hinges between floats, is necessary, or in fact desirable, as the waler system has proven itself under the harshest tests nature can deliver.” The Port should maintain these best practices in dock connectivity as they plan and complete their refloats for both marinas.

Install Tsunami Signs

Installing tsunami signs is one of the easiest and most cost-effective mitigation actions that a port or marina can take to reduce tsunami casualties. Signage can help educate port and marina users of the tsunami danger in the area and direct individuals to higher ground during an evacuation. Signage posted along roadways and trails alerts people that they are entering or leaving a tsunami inundation zone, so they know to evacuate if a tsunami warning is issued. Signage helps people find and follow established evacuation routes quickly during an evacuation. Signs are generally cheap, installation is easy, and upkeep is minimal.

Figure 60. The five types of tsunami signs used in Washington State. Evacuation sign arrows are not pictured (WA EMD)

Several different types of tsunami signs are used in Washington state (see figure 60). Blue, circular Tsunami Evacuation Route signs are usually accompanied by white arrows for directionality (not pictured) to guide people out of the inundation zone to high ground. Blue, rectangular Tsunami Hazard Zone signs provide general awareness that people are located within a tsunami inundation zone. White, rectangular Assembly Area signs are used to identify official tsunami assembly areas within communities. Hexagonal Leaving Tsunami Hazard Zone and Entering Tsunami Hazard Zone signs notify the public when they are entering or exiting the tsunami inundation zone and aid in both general awareness and evacuation.

Figure 61: Tsunami kiosk featuring evacuation route in Oceanside, CA.

Additionally, more informational signage can be created to educate and inform people of anticipated tsunami inundation extent, evacuation route maps, and general tsunami information. Many coastal communities with tsunami danger have built informational kiosks and other wayfinding resources to inform the public of tsunami dangers, such as the evacuation kiosk shown in Figure 61.

This action is feasible

Port Angeles currently has seven "Tsunami Evacuation Route" signs installed, with no other sign types installed (Tsunami Hazard Zone, Assembly Area, etc.). Based on the Tsunami Wayfinding Assessment completed by WA EMD in partnership with University of Washington (UW) graduate and undergraduate students, the Port Angeles area needs 40 additional tsunami evacuation signs and assembly area signs combined (with 17 rated as Tier 1, or essential for successful pedestrian evacuation). Clallam County currently has enough tsunami evacuation route signs to fill the Tier 1 needs and should work with the City of Port Angeles to ensure mapped evacuation routes are fully covered.

Once evacuation routes have been solidified and signs have been installed from beginning (waterfront) to end (official or unofficial assembly area), the Port should work with City and County Emergency Management on other opportunities for additional signage. For example, the Port and City expressed interest in adding an “Entering Tsunami Hazard Zone” sign for drivers coming into the downtown area via Highway 101 and adding evacuation route signs to parts of the Olympic Discovery Trail to help expand awareness of the tsunami hazard and contribute to improved decision making for folks evacuating out of the tsunami inundation zone.

The Port has informational kiosks located at both the John Wayne Marina and the Port Angeles Boat Haven. This is a great opportunity to educate visitors and residents on tsunami hazards and protective actions through materials such as the Tsunami Boater’s Guide developed by WA EMD. The Port should work with WA EMD, and City and County Emergency Management to evaluate potential opportunities to incorporate a full tsunami kiosk on Port property. This could be especially beneficial for the Port Angeles area, as the downtown area between the City Wharf and the Port Angeles Boat Haven has a lot of foot traffic for both residents and visitors. Incorporating tsunami evacuation maps or information would help build awareness of the hazard and reduce confusion for where to go after a major earthquake or upon receipt of a tsunami alert. The Washington State Tsunami Wayfinding Guide is a great resource for thinking beyond classic wayfinding like signage.

Two specific areas of concern remain when it comes to evacuation out of the inundation zone regardless of signage: the Marine Drive bridge next to the McKinley paper plant and moving heavy port machinery up the Tumwater Truck Route to Fairchild Airport. If the bridge over the channel entrance to the lagoon collapses during earthquake shaking, any residents and private sector personnel on the Ediz Hook face difficult decisions to reach high ground. To successfully evacuate, residents would need to cross the McKinley Paper Company property and ignore signs that state “Private Property Authorized Personnel Only” to get to the west side of the lagoon. Once they get past the industrial water treatment plant, they are faced with another decision: either travel East along the bluff for more than a mile to reach the Lower Elwha community or traverse over an empty water pipeline and try and climb a hill with an existing trail towards Crown Park that may be heavily impacted from earthquake shaking. This is one of the initial challenges that the Port should work with the City and USCG to solidify.

Increase Size and Stability of Dock Piles/Increase Height of Piles to Prevent Overtopping

Figure 62: Dock damage in Marina Chiapas after the 2017 earthquake and tsunami. (Maria Teresa Ramirez-Herrera, 2017)

Structurally, the pilings are one of the most important components of a dock. The pilings act as the dock's foundation, keeping the structure attached to the sea floor while allowing vertical movement as water levels change with waves or tides. Tsunami inundation has the potential to float docks off the top of the pilings, leaving them unattached and floating freely (Figure 62). The strong currents caused by tsunamis can also pull pilings from the ground through scouring or drag on the docks and vessels attached to them. Pilings that are pulled loose also lead to unattached docks floating freely in the dangerous waves. Untethered, freely floating docks pose a danger in a tsunami, essentially becoming massive pieces of debris moved by the waves, sometimes with vessels still attached.

To help ensure docks remain attached to the sea floor during a tsunami, ports and marinas may choose to increase the size and stability of the pilings. Installing pilings that are taller than the expected potential inundation levels will ensure docks do not float off the top of the pilings during a tsunami. Thicker pilings will resist the shearing forces from the extreme drag of the tsunami waves much better than thinner ones. Installing pilings deeper into the sediment of the sea floor can help them remain foundationally solid, more resistant to scouring, and keep them from pulling out of the soil.

This action is feasible

As currently designed, pilings at the John Wayne Marina are 16 feet taller than Mean Lower Low Water (MLLW), the average measurement of lower low water height of each tidal day and minimum elevation used in design standards. Along the Port Angeles waterfront, pilings at the Port Angeles Boat Haven Harbormaster Dock are 15 feet taller than MLLW and Terminal 1 pilings are 17 feet taller than MLLW (see figure 63).

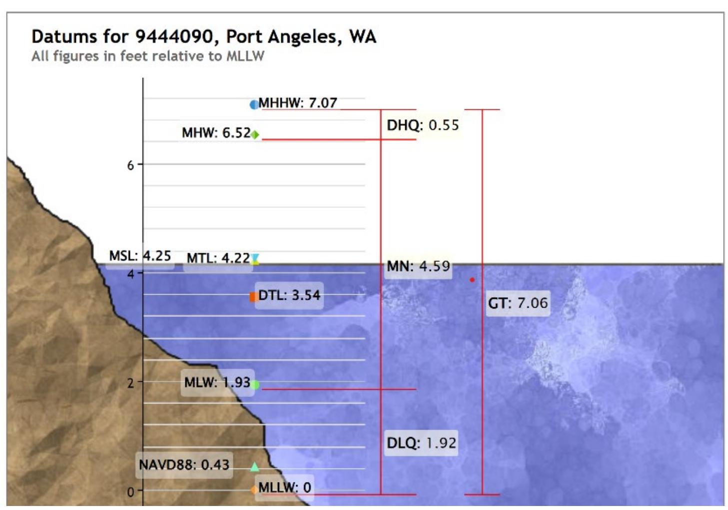


Figure 63. Tidal datums (in feet) as defined by NOAA

Ideally, dock infrastructure should be constructed to withstand the impacts of all possible tsunami scenarios. However, the Cascadia Subduction Zone scenario modeling for the Port Angeles Boat Haven area shows 20+ feet of expected inundation and current speeds far exceeding the 9-knot threshold, which would likely result in complete destruction of maritime infrastructure. The economic investment required to mitigate a CSZ tsunami would thus not be feasible. In addition, for the John Wayne Marina, the natural land formation just north of the marina and breakwater that wraps around the south and east sides of the marina provide adequate protection from the major impacts of the CSZ tsunami. Therefore, the Port should primarily consider dock infrastructure constructions that mitigate for the modeled distant Alaska tsunami impacts, as that is the maximum considered distant tsunami impacts the Port will likely experience.

To evaluate how tall the pilings should be to ensure that they are not overtopped by the rapid water level changes of distant tsunamis throughout their expected lifetime, we consider the Alaska modeling, tidal datum for the area, and expected sea level rise (SLR) over the next 60 years. Modeling for the AK scenario shows that water levels will rise between 5 – 6 feet throughout the Boat Haven area during the tsunami. Additionally, the tidal datum shows that Mean Higher High Water (MHHW) is just over 7 feet. However, events such as king tides or storm surge can further exacerbate flooding impacts. These effects were shown during the king tide event of 2022 in which waves were recorded about 9.5 feet above MLLW. To be more conservative, we can look at the highest astronomical tide of 10.51 feet above MLLW, another design standard used for maritime construction, to evaluate the highest possible tide that may occur in Port Angeles. Combining those numbers with projected sea level rise measurements for the Port Angeles area gives us a combined maximum water height of approximately 18 feet. With this information, the Port should incorporate piling heights between 18 and 20 feet taller than MLLW into their planning efforts to sufficiently mitigate distant tsunami impacts.

Figure 644. Piles in Eagle Harbor, City of Bainbridge Island, WA that incorporated SLR into their design. (WA EMD)

Given that there is currently no standard for piling widths, the Port should increase the thickness of pilings to withstand the shearing forces of increased tsunami currents, which are expected to be anywhere between 4 – 6 knots in the center of the Port Angeles Boat Haven. Communities such as Crescent City, California can provide a valuable blueprint for creating tsunami resilient docks.

The Port is currently developing plans to reconfigure and complete a float and breakwater replacement for the Port Angeles Boat Haven in 2029, with a float and piling replacement for John Wayne Marina targeted for 2035-2040 based on their 2025 budget. These projects will be funded through a combination of capital improvement funds and available grant funding.

Reduce Exposure of Petroleum/Chemical Facilities and Storage

Since ships go to ports and marinas for refueling and many routine maintenance procedures, these areas often have facilities that utilize and store petroleum and other chemical products. Some ports may even have chemical processing facilities or oil refineries in addition to normal vessel fueling facilities and manufacturing plants that utilize chemicals. Damage to or destruction of these facilities or the containers that store petroleum or chemicals during a tsunami can cause widespread hazardous contamination. Petroleum products and many other chemicals are less dense than water and will float on top of the inundating waves, then left on shore or pulled out to sea as the waves recede. Petroleum products have also been known to combust even on top of the water and can catch floating debris on fire. An inferno on top of an inundating tsunami wave or pulled out to the open sea can swiftly become an even larger disaster than the original destructive wave.

Ideally, major chemical processing facilities, refineries, and large fuel storage tanks should be located well outside the tsunami inundation zone. If that is not possible, the next best solution is to construct or retrofit those facilities to withstand a major earthquake and resulting tsunami. Smaller holding tanks and storage facilities should be considered for relocation out of the inundation zone as well; if not possible, they should be moved to locations at less risk for damage or hardened as much as possible to withstand earthquake shaking and tsunami waves.

This action is feasible

The Port's primary fuel tanks for vessel usage are buried underground, as highlighted in the response section of this document. Outside of those large fuel tanks, the largest risk of chemical spill that would impact Port property comes from the Petrocard facilities just east of the Port Angeles Boat Haven and the nearby Marathon Fuel Tank Farm, in which thousands and millions of pounds of fuel and other hazardous substances are stored, respectively. Additionally, chemicals (including fuels) stored at any tenant facilities and liveaboards or vessel owners who have chemicals stored within the marina areas may create additional risk of hazardous material spill in a tsunami. The Port should work with City and County emergency management to educate their liveaboards and vessel owners on proper chemical storage and safety guidelines and procedures through meetings and the creation of educational materials. Additionally, the Port should continue to include language in their tenant agreements to abide by federal and state requirements for proper chemical storage requirements to further reduce the risk of spill in a tsunami.

Improve Movement of Dock Along Dock/Pilings

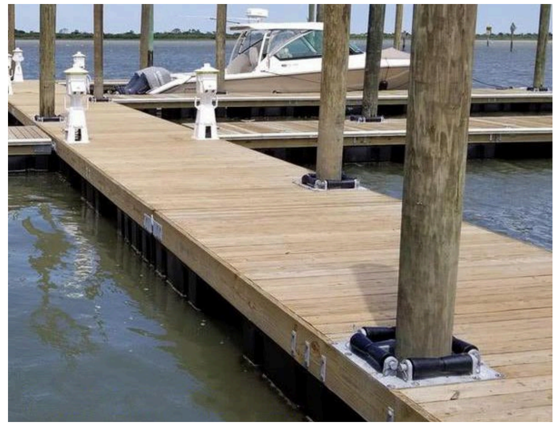


Figure 65: Floating docks with square pile guides for each piling (americanmuscledocks.com).

As with the flexibility of dock connections, one of the dangers in the rapid water level changes that come with a tsunami wave is docks not freely moving vertically along the guide of the pilings. The unpredictable waves and rapid water level changes have been known to cause the connection between docks and piles to bind. This can cause the docks to 'jam' against the pilings, leaving the dock unable to float up with the water. When docks get stuck on the piles, the water level can quickly overtop the dock surface, causing major damage.

Some hardware used to connect docks with pilings, such as simple metal hoops with little space between the dock hardware and piling, can be more prone to binding. As docks lift rapidly on one side, the other side can become wedged against the piling at an angle. The force of the water against the dock surface can bend these hoops, trapping the dock even more, or can cause the connection hardware to break, leaving the dock unattached to the piling and allowing it to float freely and become debris. Dock connections to piles that run through a hole in the dock surface are less likely to bind or break, and utilization of guide wheels or rollers helps to avoid binding issues and promote smooth movement even more (Figure 65).

This action is feasible

Figure 66. Piling at John Wayne Marina showing wear and tear from the metal piling loop during previous high tide events. (WA EMD)

The pilings at both the John Wayne Marina and the Port Angeles Boat Haven currently rely on external pilings (run on the outside of the dock) with large piling hoops to keep the docks in place. Water levels may rapidly rise and fall with distant tsunamis, king tides, and other coastal hazards, creating the need for the docks to do the same to not get overtopped and heavily damaged. John Wayne Marina has seen some significant wear and tear from these events previously (see figure 66). The distinct horizontal stress lines show that the dock itself was pulling enough on the piling itself to leave an indentation.

This problem can be alleviated with the addition of rollers to the hoop extension to allow for more freedom of movement for the dock in conjunction with rapid water level changes. With the upcoming refloats for both marinas, the Port has the opportunity to incorporate rollers into the design of their piling connections to improve the dock's resilience to tsunami impacts. These upgrades can be funded through a combination of capital improvement funds and any available grant funding that the Port pursues for this project.

Acquire Equipment/Assets to Assist Response Activities

Post-tsunami response will be a complicated effort involving many personnel and equipment. Vessels will be needed to search the water for survivors or casualties, as well as move damaged vessels, broken or detached docks, and other large debris in the area. Fireboats and other firefighting equipment will be needed to extinguish any fires that start among vessels, facilities, or floating debris. Cranes may be needed to hoist and move large debris either in the water or elsewhere on port property. Other equipment may also be required such as loaders, bulldozers, or other earth moving equipment to clear debris and allow access to all port property. Large ports and marinas may already have some of this equipment on site; smaller ports may have less equipment or may rely on equipment owned or operated by other entities.

Regardless, response will require equipment, and the more of that equipment that is either owned by or prearranged for use by the port or marina, the faster the response can begin and clean up can start. If a port does not have equipment or the means to purchase it, they should consider developing a response plan that addresses this issue, including agreements with local entities to rent, borrow, or have use of any equipment that would be needed to respond after a tsunami in their port.

This action is feasible

The Port has a variety of heavy machinery that they intend to move to high ground in case of a local CSZ tsunami. Much of the machinery does not require special licenses to operate and the Port has around ten personnel total to operate the equipment. Below is a list of current machinery that could be utilized for debris removal once the tsunami has passed:

- Log stackers - 4 Wagners, 3 L90s, and o1 L80, capable of lifting 80,000 - 90,000 lbs each (see Figure 67)
- Front end loaders - 2 John Deer 844s
- Log shovels - 4 large Doosan log shovels (two 380s and two 300s)
- Dump trucks - 2 full size dump trucks (require CDL)
- Excavator - 1 320 class excavator
- 1 Kubota Mini excavator
- Backhoe Excavator – 1 CAT 416 Backhoe

Additionally, the Port is in the process of updating their log stackers with already awarded grant funds and is planning to acquire a bulldozer and another front-end

Figure 67. One of the log loaders owned by the Port of Port Angeles (WA EMD)

loader for future use with a combination of port and grant funds. The City has vacuum trucks, dump trucks, tractors, mini excavators, and other machinery that they plan to utilize once the tsunami has passed. The Port should work with the City and County to ensure agreements are in place to utilize this machinery for more effective cleanup operations in the post-tsunami environment.

Debris Deflection Booms to Protect Docks

Debris deflection booms are installed in harbors to protect dock structures from damage caused by floating debris. Booms are installed between the open water and the docks to deflect any floating debris and prevent it from striking dock structures or moored vessels. Debris deflection booms are typically made from floating interconnected pieces of formed plastic filled with foam (much like smaller dock floats) to ensure they do not sink, as shown in Figure 68. These individual floats are strung together with a cable and attached on each end to a foundational piling that allows the floats to rise and fall with tides and waves.

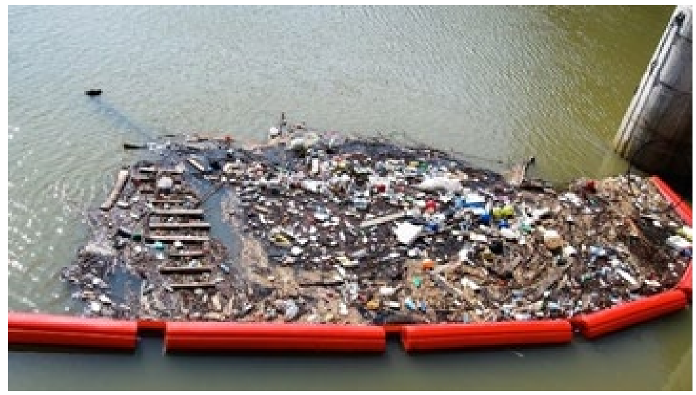


Figure 68: Debris deflection boom (Worthington Waterway Barriers).

Debris deflection booms would likely be overwhelmed by large local tsunami waves carrying immense amounts of debris but would function well to protect docks from the smaller tsunami waves and lighter amounts of debris of a distant tsunami. Even a partial reduction in the amount of debris carried on tsunami waves would help reduce damage from collisions between debris and vessels or dock structures.

This action needs review

Due to the John Wayne Marina's natural tsunami protection by the outcropping of land north of the marina, the Port Angeles Boat Haven is the only location in which placing debris deflection booms may have value for the Port. Currently, the Port relies on contractor services to acquire booms, primarily for use in oil spill response. For debris deflection, boom use is not feasible for the CSZ tsunami scenario as current speeds and water levels far exceed the capability of any boom design. However, for distant tsunamis, in which the Port would have more than four hours to respond before waves arrived, the deployment of debris deflection booms could reduce the chance of impacts to dock infrastructure and speed up the cleanup and recovery process for the Port.

Debris booms need to be able to rise much higher than typical tidal changes to accommodate the extra rise of water from tsunami waves, so they do not become over topped, eliminating their effectiveness. According to the American Society for Testing and Materials (ASTM), debris booms should be Open Water Type IV (Enhanced Performance) Exclusion booms to survive the increased current speeds and water level changes in a tsunami, as these are meant to be used in "Rough Open Water" (ASTM F625). Although a relatively inexpensive mitigation action, the Port should evaluate the associated costs, operational use, and the capacity and capabilities of their staff in tsunami response to determine the prioritization and feasibility of this effort.

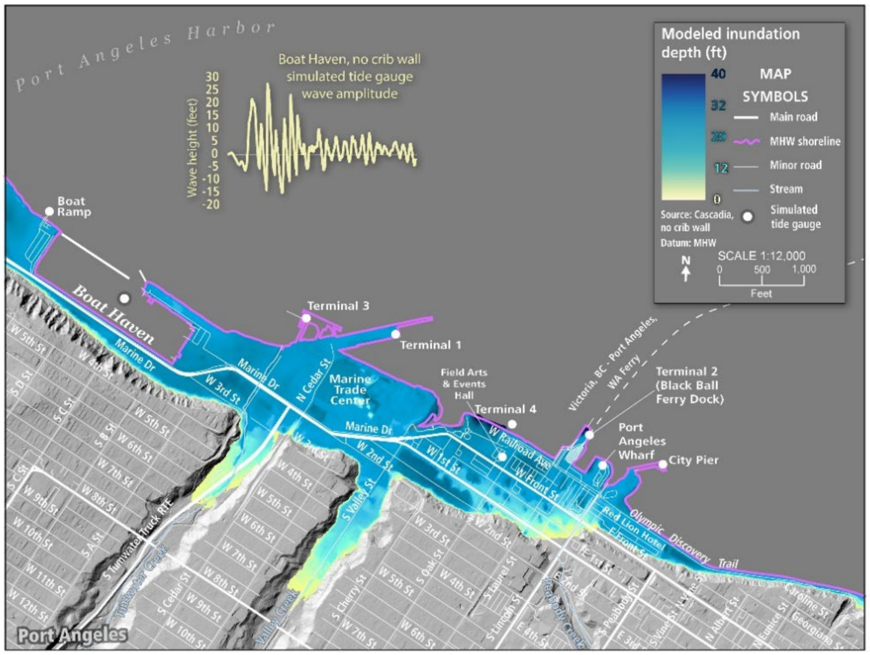
Widen Size of Harbor Entrance to Prevent Jetting

The narrow entrances of harbors act as a funnel to channel moving water into and out of harbor areas depending on wave and tide action. Typically, harbor entrances are built as an opening between breakwaters and are kept narrow to limit the rough seas passing through them. While the narrow design helps keep the harbor areas calmer during typical rough conditions, they become much more dangerous during a tsunami. The extreme water level changes and surges of water that are produced by a tsunami become amplified at narrow entrance points. Here the water speeds up dramatically while passing through these funnel areas to enter or leave the harbor. Most tsunami modeling shows the highest current velocities occur in areas constricted by narrow points the water must pass through.

In some harbors, this jetting of water through the constricted areas can be lessened by widening the harbor entrances. Widening harbor entrances is a delicate balance between mitigating the risk of extreme currents during infrequent events like tsunamis and providing shelter and lessening rough seas entering the harbor during frequent storm events. Changing or altering the size and shape of harbor entrances will also change how the tsunami waves interact within the harbor, so proposed changes should be evaluated through tsunami modeling to understand how the changes will affect the harbor and vessels in the harbor.

This action needs review

As part of the modeling for this strategy, the Washington Geological Survey ran tsunami models with and without the crib wall that protects the west side of the Port Angeles Boat Haven. As seen below, the presence of the crib wall does not have any impact on the expected inundation in either scenario. However, there is a slight reduction in current speeds around the entrance and within the west side of the Boat Haven when the crib wall is removed (see figure 69). Overall, it is difficult to determine if these changes are an artifact of the tsunami modeling itself or if the crib wall was directly responsible for the minimal changes in current speeds. Since the crib wall is approaching the end of its life cycle, and the Port is currently in plans to potentially reconfigure the Port Angeles Boat Haven as part of their refloat project, the Port can evaluate the feasibility of completely removing the breakwater (crib wall included) through both an operational day-to-day lens and a risk reduction lens. It is recommended that the Port use the modeling shown here to consider if widening the size of the harbor entrance is a worthwhile risk reduction effort for their future planning efforts.



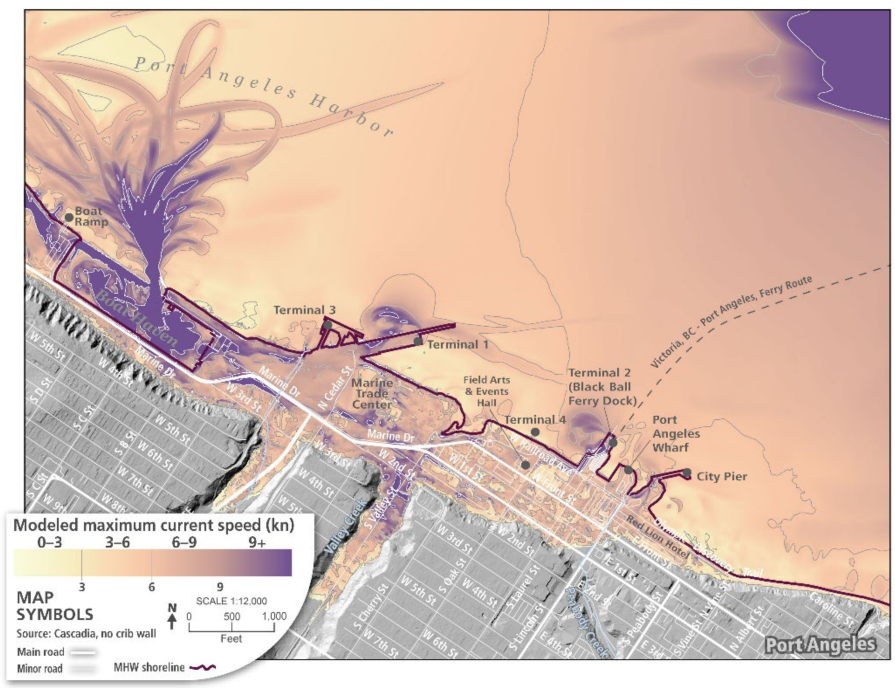


Figure 69. Tsunami inundation and current speed modeling results without the crib wall on the western breakwater. These results can be directly compared to the results here and here (Figures 25 and 33).

Construct Floodgates

Figure 70: Floodgates in Fudai, Japan stand tall after the 2011 tsunami. (NBC News)

The construction of floodgates has proven successful in several locations to lessen or eliminate inundation from tsunami waves. While the largest and most powerful tsunamis can overtop or otherwise breech floodgates, they have proven extremely effective during smaller tsunamis, and even during large tsunamis in locations with less inundation. Japan has constructed several massive floodgates that proved effective against tsunami waves, like the floodgate pictured in Figure 49. Floodgates are most effective when waterways have a narrow entrance to a bay, port, or harbor, allowing one set of gates to protect the entire area.

Construction of floodgates is likely the most complicated and labor- and time-intensive mitigation project listed in this strategy. Additionally, there are potential issues with installing floodgates: they can disrupt natural tidal movements; they require a massive physical footprint; and they need to be operable after a major earthquake to be closed before tsunami waves arrive to be effective for tsunami mitigation.

This action needs review

This type of project is not feasible for the John Wayne Marina. Due to the natural protection provided by the land just north of the marina, there is little need for a floodgate. The Port should invest in other, more effective mitigation actions.

For the Port Angeles Boat Haven, the breakwater that helps protect the west side of the marina is aging and may need to be replaced in the near future. A study titled "Breakwater Damage and the Effect of Breakwaters on Mitigation of Inundation Extent During Tsunamis: Case Study of The 2011 Great East Japan Earthquake and Tsunami" by Takagi and Bricker has suggested that fully enclosing a marina may drastically reduce the impacts of storm surge and tsunamis, as long as the protective barrier is not overtopped. Constructing a floodgate within the Port Angeles Boat Haven could be beneficial for distant tsunamis and other predictable coastal hazards (storm surge, king tides, etc.) to help reduce the impacts to port infrastructure. While the Port has expressed interest in evaluating the feasibility of a floodgate, upcoming dock infrastructure projects may adequately mitigate the impacts of distant tsunamis and render floodgates an unnecessary/duplicative investment. While a floodgate project should not precede investments into the maritime infrastructure, the port would like to revisit the possibility once the refloat project is complete.

Move Docks and Assets Away from High Hazard Zones

Once a port has identified the areas that are more likely to experience significant tsunami hazards, they can consider relocating port infrastructure away from these areas. Docks and vessels in the highest hazard areas are at the most risk of damage or destruction during a tsunami. Moving this infrastructure away from high hazard areas and into areas that are anticipated to face a lower risk can help reduce damage.

Moving docks and infrastructure in a port or marina is a substantial undertaking involving careful planning. New construction may require the shoreside to reroute walkways or build new shore anchoring systems. Old pilings would need removal and, if of sufficient size and strength, repositioning in the new location, or replacement with piles of greater height, strength, or thickness. Despite all the work involved, if a port has the space and ability to reconfigure the layout of a harbor area to eliminate docks from high hazard zones, there would be a large benefit in the reduction of damaged or destroyed vessels and infrastructure if a tsunami were to occur.

This action is not feasible

Relocating docks and assets away from high hazards zones is not feasible for either the Port Angeles Boat Haven or John Wayne Marina. The Port Angeles Boat Haven already sits behind the Ediz Hook and two breakwaters that provide adequate protection from the impacts of daily wave action. There is not a significant reduction in risk if assets were moved anywhere else along the Port Angeles waterfront, and acquiring new property would be very costly and require significant changes to Port operations. For the John Wayne Marina, as discussed throughout this strategy, the natural outcropping of land just north of the marina provides significant protection for both local and distant tsunami threats. John Wayne Marina is located in one of the safest places within Sequim Bay. For these reasons, it is recommended that the Port evaluate other tsunami mitigation actions.

Fortify and Armor Breakwaters

Figure 71: The Kamaishi breakwater, which failed during the 2011 Japanese tsunami (NY Times).

Breakwaters are designed to absorb and deflect strong wave action to protect vessels from rough seas. Unless built to extreme heights, breakwaters are unlikely to block large tsunami waves. Tsunami waves can overtop the structure, allowing inundation to enter the normally protected area. The strong waves and currents from a tsunami can also cause extreme scouring on infrastructure like breakwaters. The wave action can remove the soil that acts as the foundation of the structure and even strip away sections of the breakwater itself. Scouring and damage during a tsunami can also cause the breakwater to fail, as pictured in Figure 71, allowing even more water to flow into the area. Sudden gaps in the breakwater can also create new, unpredictable, and dangerous currents.

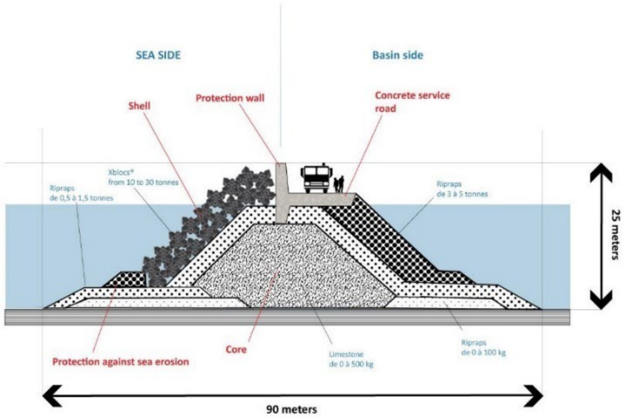


Figure 72: Diagram of fortified breakwater.

The concept behind armoring or fortifying breakwaters is simple; the entire structure is further reinforced to make it stronger, thicker, and sturdier. These enhancements are made to create more resilient structures better able to withstand the effects of a tsunami. Fortification involves strengthening the entire structure through the addition of material like rubble or concrete, increasing the size and strength of the foundation, and overall creating a larger and more sturdy structure as seen in Figure 72. Armoring involves covering the seaside of the breakwater with additional materials to help in strengthening the structure. Armoring can be done with actual rock or using wave dissipating blocks - large pre-formed concrete blocks built to be placed in an interlocking pattern less likely to break loose in strong wave and current action as shown in Figure 73.

Figure 73: Photo of fortified breakwater off marina.

Both armoring and fortifying breakwaters are time, resource, and cost intensive efforts which likely require extensive engineering, environmental assessment, approval, and construction processes. If a port has the means in the long term to engage in such a process, the benefits extend beyond just the potential to lessen tsunami damage. However, cost and effort may lead this option to only be seriously considered when building new breakwaters or when the lifespan is over for current breakwaters, and they require replacement.

This action is not feasible

The Port expressed that the breakwater around John Wayne Marina is as fortified as can be. The initial construction in the early 1980s and maintenance projects have adequately armored the breakwater and the surrounding base of the breakwater itself. Further armoring of the breakwater would not provide any additional benefits. For the Port Angeles Boat Haven breakwaters, the eastern side is in relatively good condition and is armored well. The eastern breakwater is reaching the end of its life cycle and needs to be completely replaced. The replacement of the breakwater is one of the planning considerations that the port is evaluating as part of their Port Angeles Boat Haven refloat project. The port should consider a tsunami-resistant design into their planning efforts for the eastern breakwater. Due to these factors, it is recommended that the Port utilize funds for other, more effective mitigation actions.

Construct Breakwaters Farther Away from the Port

Breakwaters confine and shelter harbors, providing protection from storm surges, strong waves, and ordinary floating debris. During a tsunami, however, these same breakwaters constrict rapidly changing water levels and current movements. Tsunami effects are amplified in confined and restricted areas, the smaller space forcing the currents to move faster and refracting waves created as the water sloshes within the enclosed basin. Constructing breakwaters farther from harbors allows more unrestricted movement of the water during an extreme tsunami (Figure 74). Enlarging the entire protected area will help slow down the extreme currents and reduce the sloshing effect by creating a larger basin for the water to move through. The locations of breakwaters for harbors are often determined by the shape of the land around them, with harbors in deep but narrower bays easier to build farther out than harbors situated on land that sticks out or runs straight.

Figure 74: Breakwater protecting the harbor of Hilo, Hawaii (Big Island Gazette)

This action is not feasible

Travis Spit, a naturally formed geographic feature, blocks a significant amount of wave action from entering Sequim Bay and the John Wayne Marina. While wave action is blocked by Travis Spit, the narrow channel it creates significantly increases the current speeds that wrap around the edge of the spit into the bay. The breakwater around John Wayne Marina cannot be extended further out into the bay as it is aligned with the natural land formation north of the marina, which provides protection from tsunami impacts. Extending the breakwater would create additional damage to not only the breakwater itself but also increases the risk of damage to the marina as well.

Ediz Hook, a naturally formed spit that undergoes beach nourishment on a routine basis for maintenance purposes, protects the Port Angeles Harbor from the wave action for water moving west through the Strait of Juan de Fuca. Every few years or so, winds out of the northeast blow waves straight into the harbor and have caused damage to the Port's terminals. While an additional breakwater that absorbs some of the wave action during these events could be beneficial for protecting terminal facilities, the costs and time associated with a project of this magnitude are not worthwhile given the low frequency of these events.

Deepen or Dredge Channels Near High Hazard Zones

The effects of a tsunami wave are strongest and most pronounced in shallower waters. Just as the wave rises higher as it enters shallower waters, pushing the water farther onto dry land, the other effects are similarly more pronounced in locations where the depth is shallower. In harbor areas, scientific mapping and modeling can identify specific locations where tsunami hazards are highest. Deepening these locations through dredging or other means will not eliminate the hazards but can help lessen their effects. Dredging or otherwise deepening channels is a complicated process that requires significant inputs of time and money.

Given the benefit from deepening channels will only alleviate some of the effects of the tsunami hazard, it is most likely not worthwhile as a standalone action. However, sedimentation builds up over time and eventually all harbors, ports, and channels require dredging for maintenance purposes. Ports could use this time of regular maintenance to utilize hazard maps, determine the areas of high hazard, and deepen them as much as feasible.

This action is not feasible

Typically, dredging projects at the Port are initiated once the sedimentation on the seafloor exceeds the authorized depth established during the permitting phase for the construction of the maritime infrastructure. The Port most recently dredged the area around Terminal 3 due to the standard using Capital Improvement funds. The timing of dredging projects can be generally estimated as the sedimentation rate in harbors is estimated at 0.2 centimeters per year.

While the Port expressed interest in future potential dredging sites, the unpredictability of future distant and local tsunamis does not provide a clear timeline to inform a dredging schedule to maximize the impacts of this mitigation action. It is recommended that the Port dredge on their usual maintenance cycle and utilize resources on other critical mitigation projects.

Section 6: Tsunami Maritime Mitigation Funding and Support

Tsunami mitigation efforts require significant resources, and securing funding is critical to ensuring communities and the built environment they depend on are more resilient for the next tsunami. The funding opportunities outlined in this section offer a range of financial support, from broad, multi-purpose grants to more focused programs aimed specifically at maritime infrastructure and disaster resilience. While this is not an exhaustive list, the programs presented here represent a starting point, drawing on lessons learned from other jurisdictions and experiences in disaster preparedness.

In addition to tsunami hazards, it's important to think of multi-hazard approaches that address other, more frequent coastal hazards, such as sea level rise driven by climate change, king tides, storm surge flooding, and erosion. By addressing multiple coastal threats simultaneously, communities can maximize the impact of their mitigation efforts. This multi-hazard approach allows for the creative application of funding opportunities that may not be specifically earmarked for tsunamis but can nonetheless be leveraged to support infrastructure improvements that enhance overall coastal resilience. For example, funding that targets sea level rise adaptation or flood control could also be used to implement tsunami mitigation solutions, creating a more comprehensive and long-term strategy for safeguarding vulnerable areas. Similarly, it is crucial when planning for other hazards to include tsunami risk in ongoing efforts, so completed projects do not further exacerbate the impacts of a tsunami.

Some programs, such as those offered by the Federal Emergency Management Agency (FEMA) and state-level initiatives, have historically funded hazard mitigation projects, while others, like those aimed at recreational or maritime infrastructure, present opportunities to creatively apply for funds that could directly improve infrastructure while simultaneously addressing tsunami-related risks. Communities are encouraged to think innovatively about how to utilize these programs and to collaborate with local, state, and federal emergency management partners to maximize the potential for funding.

As strategies evolve and new funding sources become available, this list will be expanded and refined. Whether applying for grants focused on infrastructure, public safety, or environmental preservation, the key is to explore all available avenues to strengthen tsunami resilience at the local, state, and tribal levels. In this context, considering a broader range of coastal hazards can help identify additional funding opportunities that can strengthen a community's overall preparedness and adaptability to future environmental challenges.

At the same time, grants are often hard to get due to their competitiveness and factors such as the timing of grant cycles. To be awarded federal grants, it is essential to have an eligible project, to prepare a strong and complete application, and to work closely with your local, county, tribal, and state partners. Contact the Washington State Emergency Management Division (EMD) early if your community is interested in applying for a grant.

Implementing tsunami mitigation measures requires creativity, financial resources, determination, and community buy-in. The following programs and services represent a comprehensive, yet not exhaustive, list of options to potentially fund some of these mitigation measures. You may utilize several funding options throughout the course of your project.

Potential Mitigation Funding Sources

1. Recreation Conservation Office (RCO) Grant

The Recreation and Conservation Office (RCO) provides a wide range of grant programs in Washington State aimed at conservation, recreation, and public land access. These programs support projects related to outdoor recreation, land preservation, habitat restoration, and salmon recovery. Grants can be used to purchase land, develop recreational facilities, and restore natural habitats. The Boating Infrastructure Grant Program and the Boating Facilities Program are examples of funds relevant to maritime infrastructure, focusing on developing and renovating motorized boat facilities.

- **Eligibility**: Local agencies, state agencies, tribes, and nonprofit organizations.
- **Matching Requirements**: Generally, there is a required match ranging from 25% to 50%, depending on the grant program.
- **Funding Range**: Grants typically range from $100,000 to $1.4 million depending on the project scope.
- **Application Period**: Varies by program, but many have annual deadlines.

To learn more and find specific grant funding opportunities, visit the RCO Find-A-Grant website.

2. Hazard Mitigation Assistance (HMA) Programs

FEMA's Hazard Mitigation Assistance (HMA) Programs provide pre- and post-disaster funding to reduce the risks to people and property from natural disasters. This includes funding through Flood Mitigation Assistance (FMA), and the Hazard Mitigation Grant Program (HMGP). These programs support projects that mitigate hazards such as floods, tsunamis, and earthquakes. Jurisdictions must have or be part of a FEMA-approved Hazard Mitigation Plan (HMP) to be eligible. Projects funded by federal grants will require an environmental and historic preservation review. It is worth noting that FEMA grants have undergone and are still undergoing large programmatic changes as of the publishing of this document. The following criteria can be viewed as what has historically been true for FEMA grants and seems likely to continue.

- **Eligibility**: States, local governments, tribes, and territories with a FEMA-approved hazard mitigation plan.
- **Matching Requirements**: Typically, a 25% local match is required, but economically disadvantaged communities may be eligible for a reduced match.
- **Funding Range**: Grants can range from a few thousand dollars for small community projects to multi-million-dollar awards for large-scale hazard mitigation efforts.

To learn more about HMA grants in Washington State and how the WA EMD Mitigation Assistance Grants Team can help support applications, visit mil.wa.gov/hazard-mitigation-grants or contact HMA@mil.wa.gov.

3. Port Infrastructure Development Program (PIDP) Grant

The Port Infrastructure Development Program (PIDP), administered by the U.S. Maritime Administration (MARAD), provides funding to enhance port facilities, modernize infrastructure, and improve efficiency and safety. The PIDP provides funding to ports in both urban and rural areas for planning and capital projects. It also includes a statutory set-aside for small ports to continue to improve and expand their capacity to move freight reliably and efficiently and support local and regional economies. This grant also supports projects that reduce port congestion, improve port safety and environmental sustainability, and enhance resilience against disasters.

- **Eligibility**: Public entities that own or operate port facilities, including state and local governments, tribal organizations, and port authorities.
- **Matching Requirements**: Typically requires a match from the applicant, although the percentage varies depending on the scope of the project.
- **Funding Range**: Individual awards can range from $1 million to over $50 million for large-scale port infrastructure projects.
- **Application Period**: Annual, with submission deadlines typically in the summer.

To learn more, visit maritime.dot.gov/PIDPgrants.

5. Economic Development Agency (EDA) Disaster Supplemental Grant Program

Fiscal Year 2025 Disaster Supplemental

Application Deadline: Readiness and Implementation grant applications will be accepted on a rolling basis until funds are exhausted or the NOFO is canceled.

The U.S. Economic Development Administration (EDA) is now accepting applications through the FY 2025 Disaster Supplemental Notice of Funding Opportunity (NOFO). Funded through supplemental appropriations, this grant program makes approximately $1.45 billion in disaster recovery funding available to American communities that received major disaster declarations due to hurricanes, wildfires, severe storms and flooding, tornadoes, and other natural disasters occurring in calendar years 2023 and 2024. EDA grants can be awarded to assist a wide variety of disaster recovery projects and activities, including economic recovery strategic planning grants and public works construction assistance. EDA's flexible program resources are well-suited to address the needs and priorities identified by communities and regions recovering from natural disasters.

For the current grant round Clallam County is recognized to have a natural disaster and entities are eligible to apply for funding. EDA is a good fit for tsunami and multi-hazard mitigation for ports as it helps ensure reliable, economically robust port economies following past and mitigating future disasters.

6. Better Utilizing Investments to Leverage Development (BUILD) Grant Program (Formerly known as the Rebuilding American Infrastructure with Sustainability and Equity (RAISE) Grant)

The Better Utilizing Investments to Leverage Development (BUILD) Grant is a discretionary grant program under the U.S. Department of Transportation that provides funding for critical freight and passenger transportation infrastructure projects in the U.S. This program aims to address infrastructure needs, enhance sustainability, and promote equity, particularly in historically disadvantaged communities. These funds are authorized through President Biden's Bipartisan Infrastructure Law, with ongoing support expected for the near future, though no specific expiration date is provided.

- **Eligibility**: State and local governments, counties, Tribal governments, transit agencies, and port authorities can apply. The program supports multi-modal and multi-jurisdictional projects.
- **Matching Requirements**: There is no set match percentage for BUILD grants outlined. For more information about specific matching requirements, please contact BUILDgrants@dot.gov.
- **Funding Range**: The program most recently awarded $1.32 billion for FY25, with grants supporting a wide range of project sizes. Awards for this past year(FY25) have ranged from $160,000 to $25 million, which is the maximum reward allowed.
- **Application Period**: The application period varies annually, with deadlines typically announced by the U.S. Department of Transportation. Demand for BUILD funding is high, often exceeding available funds.

To learn more, visit transportation.gov/BUILDgrants.

7. Oil Spill Liability Trust Fund (OSLTF)

The Oil Spill Liability Trust Fund (OSLTF) is a federal fund managed by the U.S. Coast Guard that provides money for oil spill prevention, response, and cleanup. This fund can be accessed to help with the costs of cleaning up oil spills or preventing spills through improved equipment and infrastructure. While the use of the OSLTF is most closely associated with discharges from ships, it has increasingly been used for discharges at industrial or onshore oil storage and production facilities.

- **Eligibility**: Public and private entities involved in spill response and cleanup, including state and local agencies, tribal organizations, and environmental groups.
- **Matching Requirements**: No match required, though funds are accessed based on the severity of the spill or prevention needs.
- **Funding Range**: Varies depending on the scale of the spill and the required response efforts.

To learn more, visit uscg.mil/Mariners/National-Pollution-Funds-Center/About_NPFC/OSLTF/.

8. National Coastal Resilience Fund

Funded by National Fish and Wildlife Foundation (NFWF), this fund invests in the implementation of nature-based solutions to enhance the resilience of coastal communities and ecosystems facing impacts from coastal hazards. This grant can fund projects in four different categories: Community and Capacity Building and Planning; Site Assessment and Preliminary Design; Final Design and Permitting; and Restoration Implementation.

- **Eligibility**: non-profit 501© organizations, state government agencies, local governments, municipal governments, Tribal governments (both federally and non-federally recognized tribes) and organizations, educational institutions, or commercial (for-profit) organizations.
- **Matching Requirements**: No match required.
- **Funding Range**: Varies year to year, the 2024 funding cycle granted $140 million.

To learn more, visit nfwf.org/programs/national-coastal-resilience-fund.

9. WA Department of Commerce Federal Funds Grant Writing Assistance Program (FFWAGP)

FFGWAGP is a program that supports access to federal funds grant writing assistance for communities across the state. The FFGWAGP is designed for Washington community-based organizations, local government agencies, ports, housing authorities, tribes, businesses, and others eligible to receive federal funds to prepare and submit grant applications.

Detailed service offerings

- **Grant application writing and development:** Assist participants by directly writing proposal narratives and completing application forms.
- **Grant application review and editing:** Strengthen participants' applications by reviewing and/or editing proposal narratives and other application materials.
- **Opportunity scan:** Explore relevant federal grant opportunities that align with participants' programming and vision.
- **FOA / NOFO Scan (Compliance and Federal Regulations):** Review project metrics, goals, objectives and outcomes developed by participants against the Funding Opportunity Announcement (FOA) or Notice of Funding Opportunity (NOFO) requirements. Provide feedback on project ideas and their alignment with relevant federal grant opportunities.
- **Stakeholder/community engagement strategy:** Provide strategies and resources to strengthen stakeholders and community engagement for the proposed project.
- **Application project management**: Design a project overview, timeline and strategy for submitting the federal grant application. This can include providing project management assistance for all or selected steps of the grant proposal development process.

10. WA Emergency Management Division Tsunami Program

The Washington Emergency Management Division (WA EMD) Tsunami Program is funded by an annual grant through the National Tsunami Hazard Mitigation Program (NTHMP), which funds tsunami preparedness, education, and mitigation efforts in states and territories across the United States. When possible, the WA EMD Tsunami Program requests funding through the NTHMP for tsunami signage, hazard mapping, and community education programs to support Washington's coastal communities. It then provides resources like signage, maps, outreach materials to local jurisdictions for free as this funding allows.

For more information about what kinds of resources the WA EMD Tsunami Program can provide, reach out to Public.Education@mil.wa.gov.

11. Coastal Hazards Organizational Resilience Team (COHORT)

The Coastal Hazards Organizational Resilience Team (COHORT) was developed in response to coastal communities' request for the state to help address the growing severity of natural hazards, which include flooding, erosion, sea level rise, landslides, and a Cascadia earthquake and tsunami event. The team is composed of representatives from Washington Sea Grant, The Department of Ecology, Washington State University Extension, and Washington Emergency Management Division.

What COHORT Offers in the Short Term:

- Grant development support and review
- Attend community events to build knowledge of needs and provide presentations on resilience
- Connect partners with resources

What COHORT Offers in the Long Term:

- Develop and shepherd grants for coastal resilience projects, ideally at the watershed level
- Technical assistance to scope and design projects
- Enhance long-term community-centered capacity
- Develop trusting and mutually beneficial multi-partner relationships

To learn more, visit the COHORT Website or check out their Intake Form.

12. Coastal Hazards Resilience Network (CHRN)

The goal of the Coastal Hazards Resilience Network (CHRN) is to strengthen the resilience of Washington's coastal communities through collaboration, education, and knowledge exchange. This website provides a curated selection of relevant science, best practices, and other resources related to coastal hazards in Washington. CHRN provides communities with webinars, access to a network of resilience practitioners in the state, an annual meeting, a resource library, and many other resources.

Letters of Support for Tsunami Mitigation and Response Initiatives

Letters of support from government agencies, academic institutions, and subject matter experts are instrumental in strengthening grant and funding applications, as they demonstrate broad-based support and alignment with regional or national priorities. These letters not only provide credibility but also affirm the significance of proposed projects in addressing critical issues like tsunami mitigation, response, and preparedness.

For instance, the Port of Neah Bay recently included letters of support in their Port Infrastructure Development Program (PIDP) application, which is currently under review by the U.S. Department of Transportation. These letters (as shown in the Appendix 3), provided by key partners such as WA EMD and the Washington Geological Survey (WGS), emphasized the strategic importance of the Port's infrastructure upgrades in the context of regional disaster preparedness and maritime resilience.

The letters of support for the Port of Neah Bay's PIDP application are included in the annex and serve as excellent templates for similar efforts. They showcase how to effectively align project objectives with broader disaster mitigation goals, while also leveraging the expertise and endorsement of government agencies and subject matter experts. These letters can provide a model for how to structure future letters of support, ensuring they highlight key initiatives, reference guiding materials, and underscore the relevance of the project to regional, state, and national priorities.

If you are pursuing funding that could benefit from a letter of support, you are encouraged to contact the WA EMD tsunami program via **public.education@mil.wa.gov**. Providing detailed project information to the agency writing the letter will enable them to tailor their support to your specific initiatives, thus enhancing the strength and relevance of the letter.

View examples of letters of support from WGS and WA EMD, included in the annex, to further guide your efforts in crafting a successful request.

Section 7: Conclusion and Next Steps

The maritime community of Port Angeles Harbor and the John Wayne Marina faces significant risks from tsunamis and earthquakes, with potential impacts on infrastructure, vessels, and public safety. These hazards, stemming chiefly from the Alaska Aleutian Subduction Zone (AASZ) and Cascadia Subduction Zone (CSZ) tsunami scenarios, underscore the importance of proactive planning and mitigation. While these risks pose challenges, they also present opportunities to further enhance the resilience of each area through targeted mitigation measures and refined response strategies.

The Port of Port Angeles has already demonstrated strong forward thinking when it comes to strengthening dock infrastructure by incorporating best practices in floatation, interconnectivity, and cleat design and maintenance. These completed measures serve as examples of how thoughtful design and easy investments can enhance safety. The response and mitigation measures outlined below represent the next level in advancing the Port's preparedness. 'Feasible' actions are practical and easily implementable and thus should be addressed first. Actions categorized as 'Needs Review' may require further consideration and adaptation to address specific considerations unique to the Port of Port Angeles.

Summary of Key Response Actions

Of the 16 tsunami response actions evaluated for the Port of Port Angeles, nine were deemed 'Feasible' and three as 'Needs Review'. These response actions are critical, particularly for the distant AASZ scenario in which waves will not arrive for more than four hours after the earthquake ruptures. These actions will require effective communication, training, and exercising to enhance the coordination and efficiency of tsunami response for the Port of Port Angeles. Strengthening 'Feasible' actions and further exploring actions that 'Need Review' will improve the resilience of the Port and further reduce the impacts of future tsunami events.

Below is a summary of response actions recommended for the Port of Port Angeles, categorized by feasibility:

Feasible Response Measures

1. Shut Down Port Infrastructure Before Tsunami Arrives
2. Personal Floatation Devices/Vests for Port Staff
3. Informing and Coordinating with Key First Responders During a Tsunami
4. Remove or Secure Hazardous Materials Used or Owned by the Port
5. Identify Boat Owners/Individuals Who Live Aboard Vessels and Establish Notification Processes
6. Restrict Traffic Entering the Port by Land and Aid in Traffic Evacuation
7. Pre-Stage Emergency Equipment Outside Affected Area
8. Pre-Identify Personnel to Assist in Rescue, Survey, and Salvage Efforts
9. Secure Moorings of Port Owned Vessels

Actions that Need Review

1. Evacuate Public/Vehicles from Waterfront Areas
2. Activate Incident Command at Evacuation Sites
3. Activate Mutual Aid System as Necessary

Summary of Key Mitigation Actions

Of the 15 tsunami mitigation actions evaluated for the Port of Port Angeles, five were deemed 'Feasible' and three as 'Needs Review.' In addition, three were deemed 'Complete.' Completing these actions and sharing best practices with other port jurisdictions will significantly enhance efforts to reduce tsunami impacts to maritime infrastructure and tenant properties and reduce potential casualties along the Port Angeles Waterfront and in the John Wayne Marina. While some mitigation actions may require substantially more resources and support to complete, each action taken will help create a more resilient port for the community.

The Port of Port Angeles has already taken significant strides to strengthen their maritime infrastructure, with additional opportunity to incorporate some of these key actions into upcoming projects. By showcasing these completed measures, the City of Port Angeles can demonstrate practical, achievable steps that other maritime communities can emulate in their efforts to mitigate tsunami risks.

Below is the summary of mitigation actions recommended for the Port of Port Angeles, categorized by feasibility:

Completed Mitigation Actions

1. Strengthen Cleats and Single Point Moorings
2. Improve Floatation Portions of Docks
3. Increase Flexibility of Interconnected Docks and Dock Fingers

Feasible Mitigation Actions

1. Install Tsunami Signs
2. Increase Size and Stability of Dock Piles/Increase Height of Piles to Prevent Overtopping
3. Reduce Exposure of Petroleum/Chemical Facilities and Storage
4. Improve Movement of Dock Along Piles
5. Acquire Equipment/Assets to Assist Response Activities

Mitigation Actions that Need Review

1. Install Debris Deflection Booms to Protect Docks
2. Widen Size of Harbor Entrance to Prevent Jetting
3. Construct Floodgates

The mitigation and response actions outlined in this strategy provide a roadmap for enhancing the Port of Port Angeles' resilience, protecting the maritime community, and preserving functionality during and after a disaster. Partnerships with agencies such as

Washington Emergency Management Division, Washington Geological Survey, and federal entities like FEMA or the Department of Transportation can help secure the resources necessary to implement these projects. By continuing to prioritize preparedness, investing in infrastructure, and engaging with stakeholders at all levels, the Port of Port Angeles can build on its successes and serve as a model for other coastal communities. This commitment to continuous improvement will ensure that the Port remains ready to meet future hazards while safeguarding the safety and well-being of its residents and visitors.