Tsunami Maritime Response and Mitigation Strategy: Makah Tribe's Port of Neah Bay

Neah Bay, Washington

2024

Prepared for:
The Port of Neah Bay and the Makah Tribe

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This item was funded by NOAA Award #NA21NWS4670014. 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 Neah Bay and the Makah Tribe. 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:

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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 activities, such as those from the Cascadia Subduction Zone (CSZ), can swiftly endanger coastal communities, with waves arriving within minutes to hours. Conversely, distant tsunamis originating from events in the broader Pacific Ocean basin, notably from Alaska, present longer arrival times 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 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.

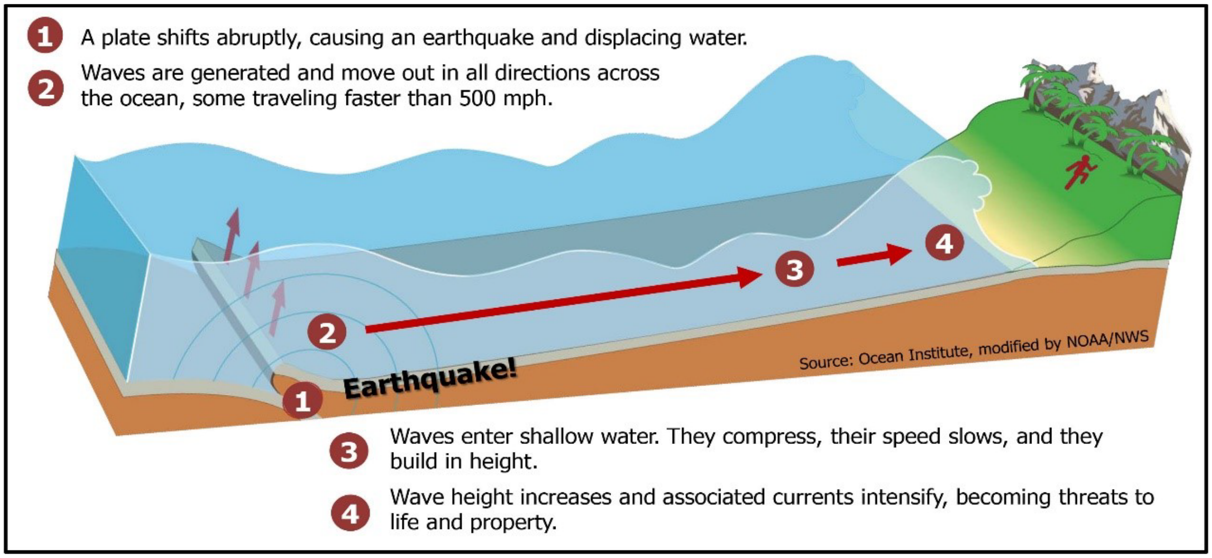

Figure 1: Earthquake generated tsunami diagram (Ocean Institute and NOAA/NWS).

Tsunamis triggered by earthquakes pose the greatest risk to Washington's coasts. 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

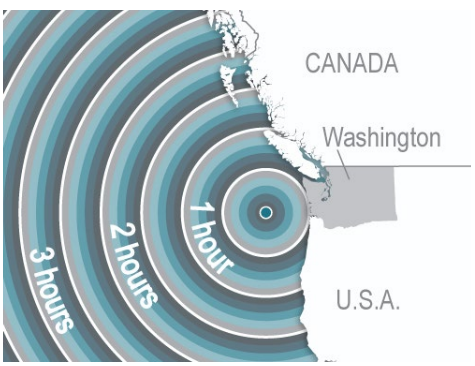

Figure 2: The wave arrival times of a local tsunami off the coast of Washington State. (WA Geological Survey 2021)

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 often caused by large underwater earthquakes along the Cascadia Subduction Zone (CSZ) fault, upper plate crustal faults, and/or landslides. The risk from a local source tsunami tends to be very high due to the first waves arriving within minutes to a couple of hours. The waves can be potentially dozens of feet high and the current speeds very fast, 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 could produce catastrophic tsunami waves that hit the outer coast within 10-20 minutes in some locations. These waves would then hit low-lying parts of the northern inland waters and Puget Sound within two hours or more. Strong currents and water level changes would continue for 12-24 hours or longer. Additionally, earthquake shaking has the potential to cause slope failures, leading to landslide-induced tsunamis with no warning and immediate impacts. Aftershocks of sufficient size may also produce tsunamis in the days, weeks, and months following a major CSZ earthquake.

Distant Source Tsunamis

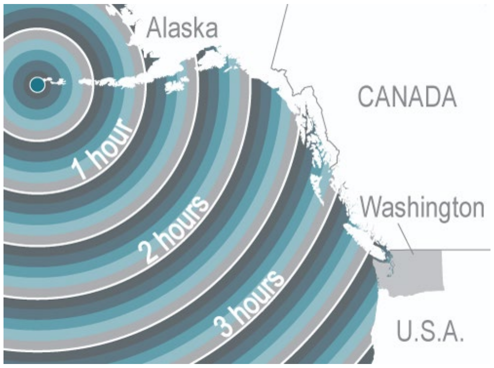

Figure 3: The wave arrival times of a distant tsunami originating off the coast of Alaska. (WA Geological Survey 2021)

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 risk from a distant source tsunami is 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 to get to high ground than a tsunami originating off the coast of Alaska where waves would arrive in Washington within 3.5-4 hours.

Alaska is Washington's closest and therefore 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

For both local and distant source tsunamis, there is always the possibility that you may not receive an official tsunami alert. 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 National Tsunami Warning Center (NTWC), National Weather Service (NWS), United States Coast Guard (USCG), Federal Emergency Management Agency (FEMA), Washington State Emergency Operation Center (SEOC), Tribes, and local jurisdictions. Figure 4 shows a summary diagram of how tsunami alert dissemination works in Washington state. 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.

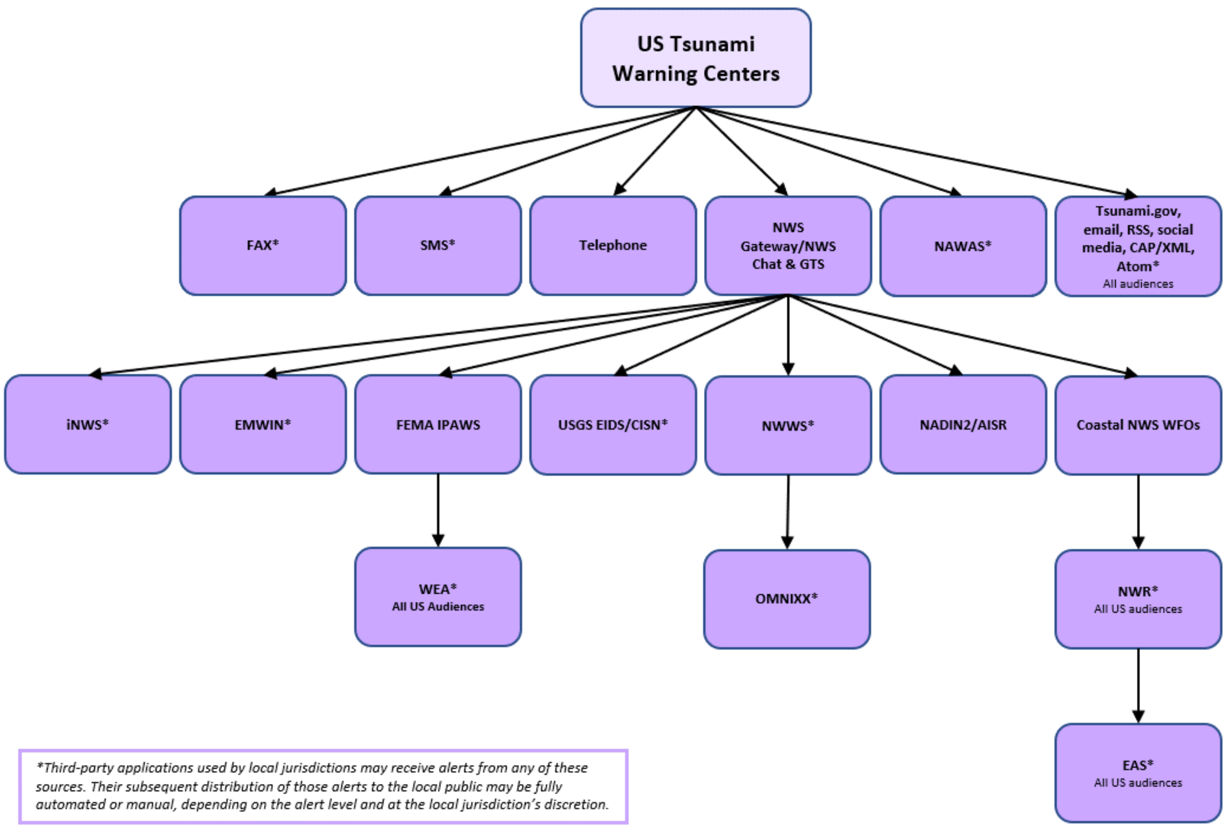

Figure 4: Diagram of tsunami alert dissemination (WA EMD 2024).

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

Tsunami Alert Messages

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 5.

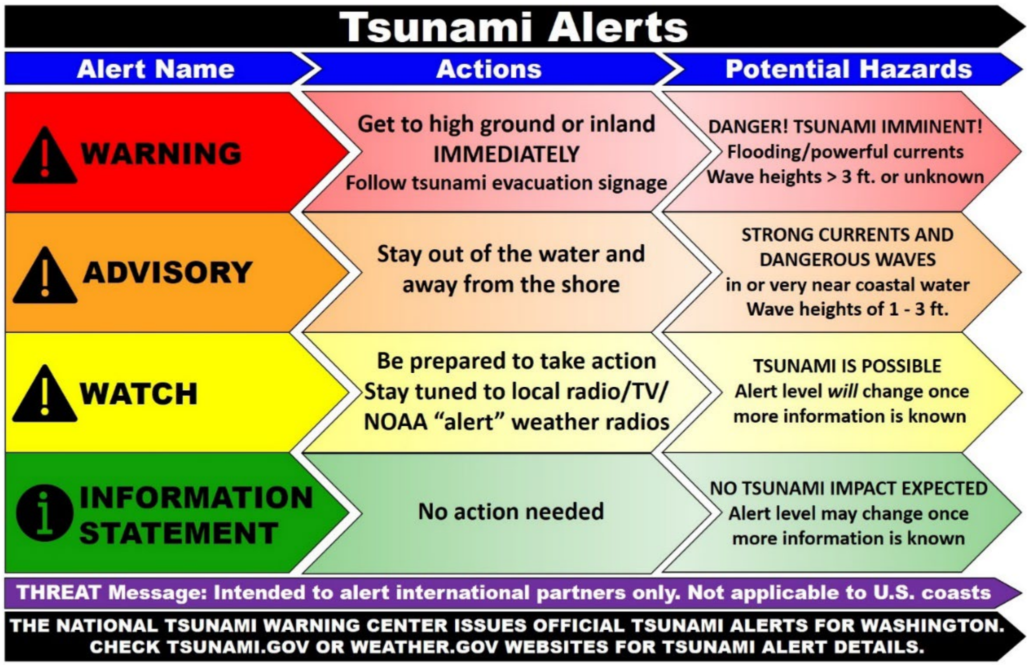

Figure 5: Official tsunami alert levels, associated effects, and protective actions to be taken.

Based on seismic data analysis or forecasted wave amplitude (which is dependent on whether NTWC has obtained sea level data), NTWC will issue the appropriate alert. Warnings and advisories recommend that protective action be taken. Watches are issued when a tsunamigenic earthquake happens but there is not enough information yet to confirm a tsunami has been generated. Watches are intended to notify emergency management officials and the public to prepare to take action and stay tuned into official sources for updates. Once the danger level is determined, the watch is upgraded to a warning or advisory, or canceled. Information Statements can also be issued on their own or precede each of the other alert levels. The full definition of each message is given below:

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 warning centers issue a tsunami warning if the forecast or observed tsunami height exceeds 1.0 meter (3.3 feet) 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 warning centers issue a tsunami advisory if the forecast or observed tsunami height exceeds 0.3 meter (about 1 foot) or is less than 1.0 meter (3.3 feet).

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 destructive 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 Radios
- Marine Radios
- Vessel Traffic Service (VTS)
- Interactive NWS
- All Hazard Alert Broadcast (AHAB) Sirens

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 tsunamis' specific 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 6: Damage in Crescent City, California, from the 2011 Japan tsunami, about 10 hours after the initial earthquake. (Craig Miller/KQED)

Tsunamis pose many significant hazards for boaters and their vessels and drag massive amounts of dangerous debris into the water (Figure 9). Sudden large fluctuations in water level can cause unprepared and unaware vessels to be quickly swamped with water and/or washed onto the 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 rapidly arrives (Figure 6). 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 are complex coastal waves that can capsize boats and pose a danger to navigation (Figure 7).

Figure 7: Standing tsunami bore wave in Sunaoshi River, Miyagi Prefecture, Japan 2016. (Miyagi Prefectural Police / Kyodo / Reuters)

Tsunamis can create strong and dangerous currents with speeds greater than 9 knots above normal currents that pose serious risk to vessels and maritime facilities. 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 8) which can 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.

Figure 8: Whirlpools forming off Japan's coast after the 2011 tsunami. (Yoiumri / Reuters)

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

Figure 10: Docks broken from Japan 2011 distant tsunami in Brookings OR. (USCG / Group Air Station North Bend)

Figure 11: Ship lifted on to land by tsunami waves in Japan (Telegraph.co.uk/EPA)

All the above risks also exist inside harbor and port areas. The extreme water level fluctuations during a tsunami have the potential for docks to overtop pilings, become detached from the shore or sea floor, or break apart in sections (Figure 10). Vessels can be grounded 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 11). 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. All these hazards can exist for 12-24 hours or more.

Summary of Tsunami Hazards that can Directly Affect Marine 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, causing problems for boaters who take their vessels offshore

Current Velocity, Areas of Dangerous and Unpredictable Currents, and the Relationship Between Current Speed and Harbor 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 12: Current velocity and associated damage(Pat Lynett, 2014).

Tsunami damage inside harbors can be directly attributed to strong currents. These 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 12).

One such generality is that the faster the current speeds the greater the chance and severity of damage. Beginning at ~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 current speeds reach ~9 knots or greater the risk of complete destruction becomes extreme to all maritime infrastructure and vessels. 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).

Actionable Tsunami Alert Levels

Tsunami warnings and advisories are the two actionable alert levels for 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.

Sign up to receive notifications from the National Tsunami Warning Center (NTWC) in Palmer, Alaska at the following website: ntwc.ncep.noaa.gov/?page=productRetrieval.

NTWC issues two types of bulletins that require action by the Washington maritime community:

Tsunami Warnings	Tsunami Advisories
Tsunami wave heights could exceed 3 feet in harbors near the open coast, indicating very strong, dangerous currents and inundation of dry land is anticipated.	Peak tsunami wave heights of 1 to 3 feet are expected, indicating strong and dangerous currents may be produced in harbors near the open coast.
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.

Actionable Natural Warning Signs for Tsunamis

The earthquake itself is the warning for a local tsunami. There may not be enough time to receive an official tsunami alert. There will not be shaking for a distant tsunami so you will need to rely on official alerts. Be alert for the earthquake and other tsunami natural warning signs:

Onshore

- Strong and/or long ground shaking (*only for local tsunamis*)
- Loud roar from the ocean
- Water rapidly receding, possibly exposing the sea floor
- Wall of water surging towards shore faster than any tide

Offshore

- You may feel the earthquake through the hull of your vessel (*only for local tsunamis*)
- You may see a rapid or extreme shift in currents and simultaneous changes in wind wave heights

General Guidance on Response to a Local Tsunami (Natural Warning Signs or Official Tsunami Warning)

Because you may have only minutes to act, it is important to have a plan in advance that includes a quick way to release commercial fishing gear so that your boat is not dragged down by currents, and at least 3 days of food, fuel, and water stored on your vessel.

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:

- Use your best judgement to decide between the two options – safely beach/dock your vessel and evacuate on foot to high ground or get to minimum offshore safe depth.
- 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:

- 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). If you can beach or dock your vessel within 10 minutes of a natural warning and evacuate on foot to high ground, this is your best option. If that is not possible, head to water that is deeper than 100 fathoms, keeping 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 tsunamis.

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.
- 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 in Alaska from the March 28, 1964, Alaska Tsunami

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.

The primary lesson was that there was INSUFFICIENT time for harbor personnel or vessel captains/owners to do 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.

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

During the tsunami (tsunami advisory)

- Evacuate from all structures and vessels in the water.
- Access of public along waterfront areas will be limited by local authorities.
- All personnel working on or near the water should wear personal floatation devices.
- Port authorities will shut off fuel to fuel docks, and all electrical and water services to all docks.
- Secure and strengthen all mooring lines throughout harbor, specifically areas near entrances or narrow constrictions.
- *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 for possible Urgent Marine Information Broadcast from the US Coast Guard.
    - Monitor VHF FM Channel 16 and the marine WX channels for periodic updates of tsunami and general weather conditions; additional information will be available from NOAA Weather Radio.
    - 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.
    - If conditions do not permit, dock your boat and head for inland to high ground.

After the tsunami (tsunami advisory)

- Mariners at sea should monitor VHF Channel 16 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. Port authorities will not allow public to reenter structures and vessels in the water until advisory is cancelled and conditions are safe.

During the tsunami (tsunami warning)

- Access of public along waterfront areas will be limited by local authorities.
- Port authorities will shut off fuel to fuel docks, and all electrical and water services to all docks.
- *If you are on the water:*
    - Prepare for heavy seas and currents. Maintain extra vigilance and monitor VHF Channel 16 for possible Urgent Marine Information Broadcast from the US Coast Guard.
    - Monitor VHF FM Channel 16 and the marine WX channels for periodic updates of tsunami and general weather conditions; additional information will be available from NOAA Weather Radio.

  - 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 conditions do not permit, dock your boat and head for inland to high ground.
- For the 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. There may also be vessel congestion in the harbor as ships, barges, and other vessels attempt to depart at the same time. All vessels should monitor VHF Channel 16 and use extreme caution. NEVER impede another vessel.
- 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.

After the tsunami (tsunami warning)

- Mariners at sea should monitor VHF Channel 16 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 Northern California from the March 11, 2011 Japanese 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.

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.

Boater 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 amount of provisions, fuel, and equipment on board; tide stage and conditions on the sea; and whether the vessel has adequate communication with other nearby vessels and authorities on shore (Figure 13).

In summary, 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. However, in situations of uncertainty or doubt, it is strongly advised to err on the side of caution and seek shelter on shore or dock the vessel. Prioritizing the safety of all individuals on board and minimizing risks should guide decision-making processes during such critical moments at sea.

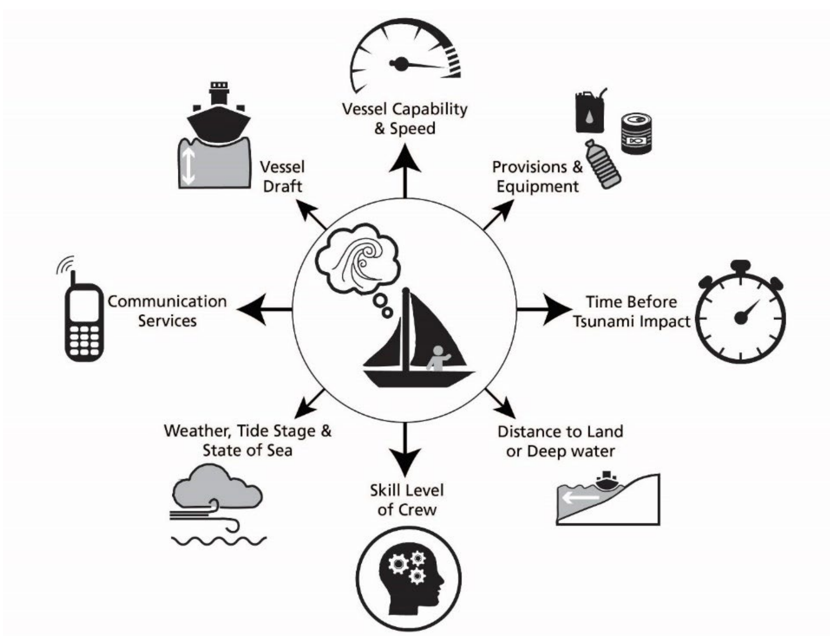

Figure 13: Considerations for boaters who are already offshore during a tsunami (WA Geological Survey).

Section 3: Tsunami Maritime Hazard and Risk Assessment for The Port of Neah Bay

Section 3 focuses on the specific tsunami maritime hazards and risks to the Port of Neah Bay, first by introducing baseline information about the Port and 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 modeling results offer valuable insights into the potential impact of tsunamis on the maritime infrastructure of the Port of Neah Bay.

The study presents tsunami modeling results from the most likely tsunamigenic scenarios for this region, including a local magnitude 9.0 earthquake along the Cascadia Subduction Zone and a distant magnitude 9.2 earthquake along the Alaska-Aleutian Subduction Zone. The results cover onshore inundation depths, tsunami current speeds, and minimum offshore water depths for both earthquake scenarios. Synthetic tide gauge data recorded over simulated time provides insights into when tsunami waves arrive, the timing of the largest wave crests and troughs, and how long impacts may persist.

Looking out at docks in Makah Marina (Makah.com, 2024)

The Makah Tribe's Port of Neah Bay

Located at the northwesternmost point of the Olympic Peninsula, the Makah Reservation is bounded by two major water bodies: the Pacific Ocean and the Strait of Juan de Fuca. This prime location has enabled the Makah Tribe to play pivotal roles in the fishing, trade, and tourism industries, significantly boosting their economy. The Makah Indian Nation boasts impressive maritime infrastructure within Neah Bay, including the Makah Tribal Marina with approximately 200 slips accommodating a wide range of vessels. Additionally, they have a state-of-the-art ice machine dock, 120 feet long, two-lane, with five terminals, capable of holding 110 tons of ice and built to withstand the impacts of a magnitude 9 earthquake. The Makah maritime community also has a proud history full of traditions tied to the sea, such as war canoe races and whaling. Their location at the tip of the Olympic Peninsula has served as a vital hub for marine commerce and recreational activities for centuries.

The Port of Neah Bay is a vibrant maritime community that plays a crucial role in supporting the Makah Tribe's economy, culture, and lifestyle. With its rich maritime history, diverse fishing community, and modern infrastructure, the Makah Marina stands as a testament to the enduring connection between the Makah people and the sea. This dynamic port not only facilitates marine commerce and recreational activities but also preserves and honors the profound maritime heritage of the Makah Tribe. The cultural significance of the marina extends beyond its immediate economic impact, fostering a sense of identity and continuity for the Makah people. Through events like Makah Days and ongoing cultural programs, the community remains deeply engaged with its seafaring traditions, ensuring that younger generations appreciate and uphold their rich heritage. Furthermore, the Marina's role as a gateway for visitors allows for meaningful cultural exchange, where tourists can learn about and respect the Makah Tribe's history and way of life. This vibrant interplay of commerce, culture, and community makes the Port of Neah Bay a unique and vital part of the Pacific Northwest's maritime landscape, symbolizing resilience, tradition, and the enduring spirit of the Makah people.

Children participating in Makah Days Activities (Makah.com, 2024)

However, this economically strategic location also leaves the Makah people and their land vulnerable to infrequent but potentially catastrophic geological threats, like major tsunamigenic earthquakes within the Pacific Rim. Of most concern is the Cascadia subduction zone (CSZ), situated approximately 70 miles offshore from the Makah Indian Reservation. Activity at this local tectonic plate boundary could pose immediate impacts to the region, including possible local sea-level changes and tsunami inundation. Additionally, distant tsunamigenic earthquakes, such as those generated off the coast of Alaska, may also threaten the Makah Tribe. Though resilient, this area has been impacted by both local and distant tsunamis in the past (e.g., Cascadia 1700; Alaska 1964), and inevitably it will be impacted again. It is not a matter of if the next tsunami happens, but when.

This section addresses the estimated maritime tsunami hazards and their potential impact on critical maritime infrastructure within Neah Bay and the Makah Tribal Marina from two possible seismic scenarios. Scenario one represents a tsunami generated by a local magnitude 9.0 earthquake within the CSZ, and scenario two represents a tsunami triggered by a distant magnitude 9.2 earthquake within the Alaska-Aleutian subduction zone (AASZ). This Alaska earthquake scenario is similar in magnitude to the Great Alaskan earthquake from March 27, 1964; however, the area of rupture has been shifted along the AASZ to give the largest wave amplitudes offshore Washington (see Scenario One in Chamberlin and others, 2009). These two modeled earthquake scenarios represent Washington's current "maximum considered" tsunami hazard from a local or distant event and have been adopted for preparedness, mitigation, response, and recovery planning statewide.

The chosen study area for this Tsunami Maritime Strategy focuses on the Port of Neah Bay's Makah Marina and Makah Bay, encompassing these key sites within its scope for modeling purposes (as shown in Figure 14). This site-specific modeling, which considers factors such as topography, bathymetry, and coastal dynamics, is vital to the assessment of potential tsunami impacts on these 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 Makah Tribe's Port of Neah Bay and its surrounding maritime community against the threat of tsunamis.

Study Area and Data Outline

The study area for this maritime assessment includes 1) the Port of Neah Bay, including the Makah Tribal Marina and Coast Guard station, and 2) the Makah Indian Nation's headquarter buildings located northeast of the mouth of the Wa'atch River that flows into Makah Bay (Figure 14). We present estimated tsunami impacts such as maximum onshore inundation depths, maximum current speeds, and minimum offshore water depths at either the Mean High Water (MHW) or Mean Low Water (MLW) tide-stages. Additionally, we also provide these same data at a more regional scale, encompassing Cape Flattery, to provide an overview of tsunami impacts to the area at large. All tsunami models were generated on 1/9th arc-second elevation grids, and simulated for 10 and 14 hours, respectively for the local CSZ and distant AASZ scenarios.

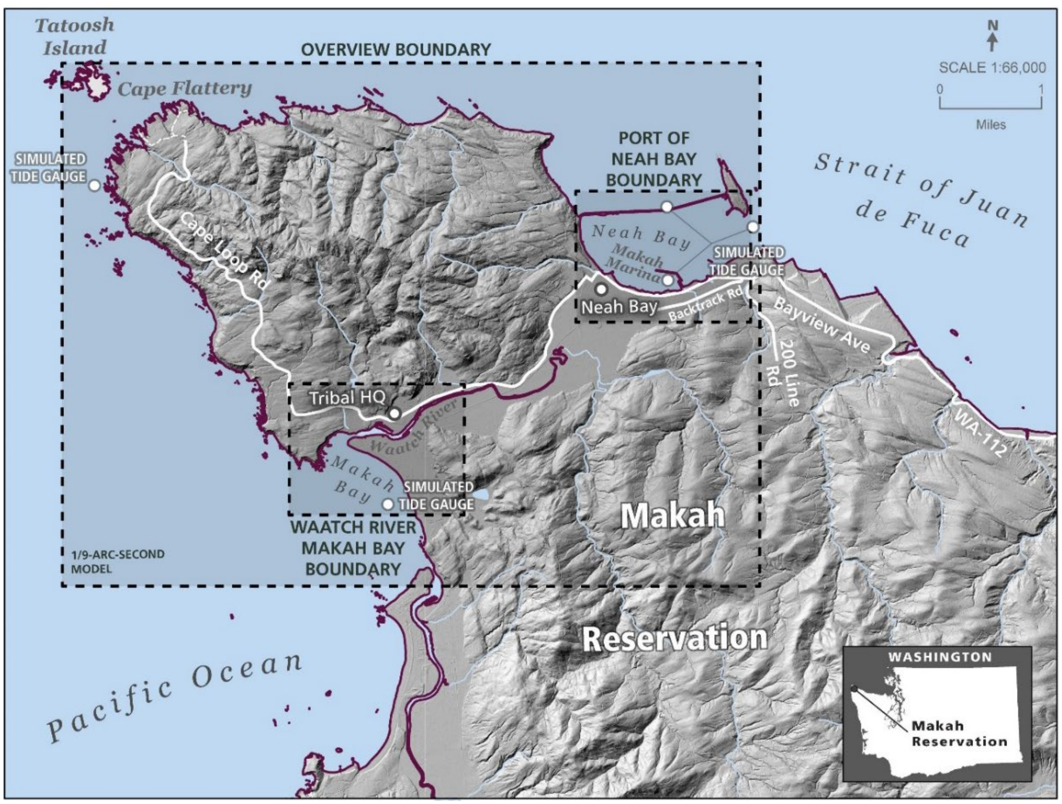

Figure 14: Study area of the Makah Indian Nation, Port of Neah Bay, and Makah Tribal Marina Tsunami Maritime Response and Mitigation Strategy.

Maximum Onshore Tsunami Inundation

Potential tsunami inundation (tsunami-induced flooding over previously dry land) poses significant risk to much of the built-up Makah Reservation tribal lands. 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 (providing a conservative result).

Cascadia Subduction Zone

When simulating the CSZ earthquake scenario, the ensuing modeled tsunami inundates the entire Wa'atch River valley (Figure 15). Maximum offshore wave heights range from ~30 feet on the Neah Bay side (Figure 16), and ~45 feet on the Makah Bay side (Figure 17). Given the short amount of time until the waves arrive and the estimated wave heights, boat owners on shore should immediately head to high ground once the shaking stops. It would be dangerous for boat owners to attempt to take their boat out to deeper water. Additionally, the first wave is not always the highest and waves can continue for 12-24 plus hours following the earthquake. With the expected wave heights, docks will likely overtop pilings, vessels may be washed onshore and grounded, and any boats on the water could capsize. The waves will carry significant amounts of debris, create dangerous conditions, and cause immense damage to the maritime infrastructure and the surrounding area.

Wave heights of this size suggest that the Waadah Island Jetty would be overtopped and likely destroyed. Water would then enter Neah Bay proper from the north, in addition to waves wrapping around Waadah Island from the east, and eventual water arriving up the Wa'atch Prairie from the southwest. This all leads to extreme onshore flooding, inundating nearly all incorporated Neah Bay. Overall modeled inundation depths vary and are dependent on the local topography, though on average these depths range from 6-16 feet in Neah Bay (Figure 16), and 28-33 feet near the Tribal Headquarters along Resort Drive in the Wa'atch River Makah Bay area (Figure 17). Additionally, the ice dock within Neah Bay could be at risk of failure as it is specified to withstand a 15-foot tsunami, a height this modeled scenario exceeds.

Response time in a CSZ tsunami event will be extremely limited. It is assumed that shaking from the earthquake may last from 3-6 minutes and tsunami inundation would start to impinge on the Makah Bay and Neah Bay shorelines in approximately 15 and 20 minutes from the start of the earthquake shaking. This initial tsunami wave quickly ramps in wave height and exceeds 1 foot at the tribal headquarters on Resort Drive and the Makah Tribal Marina building in just ~20 minutes at both locations. When considering the total duration of earthquake shaking, people may only have 15 minutes or less to evacuate to high ground once it is safe to do so depending on their location.

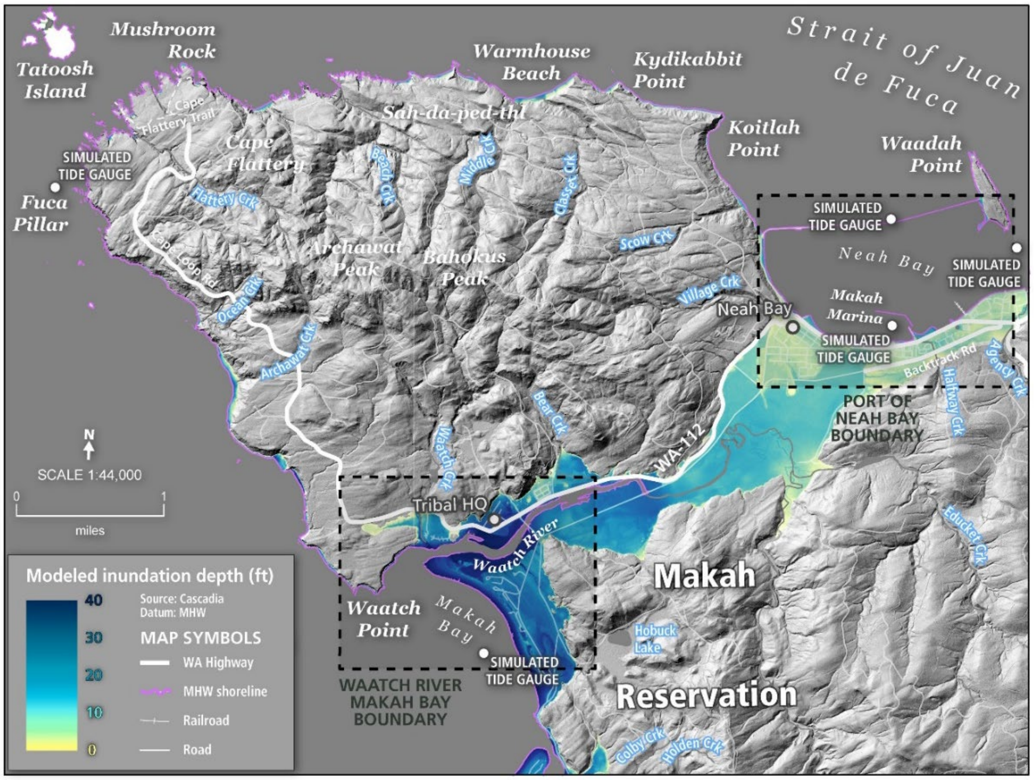

Figure 15: Overview of the maximum modeled tsunami inundation generated by a large magnitude 9.0 Cascadia subduction zone earthquake scenario. Tidal datum: Mean High Water. Model resolution: 1/9th arc-second (~3 meters).

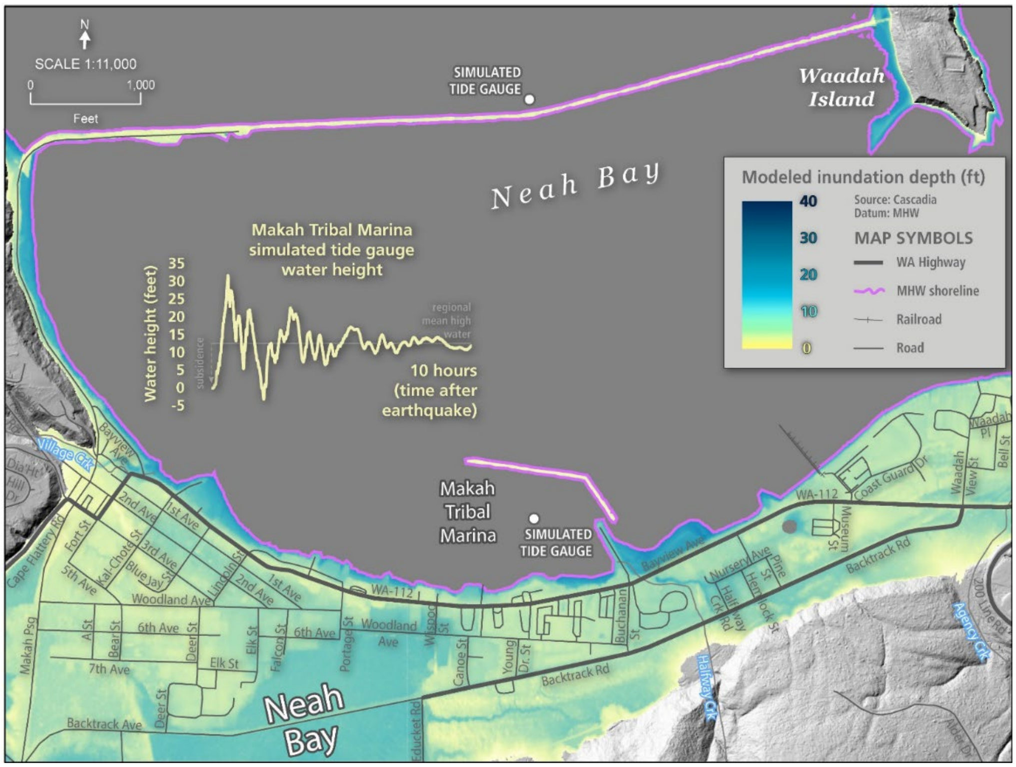

Figure 16: Modeled maximum tsunami inundation depths over land within the Port of Neah Bay boundary area from the Cascadia subduction zone earthquake scenario. Offshore tsunami wave heights within the Makah Tribal Marina approach ~20 feet and onshore flooding depths generally range from 6-16 feet. Tidal datum: Mean High Water. Model resolution: 1/9th arc-second (~3 meters).

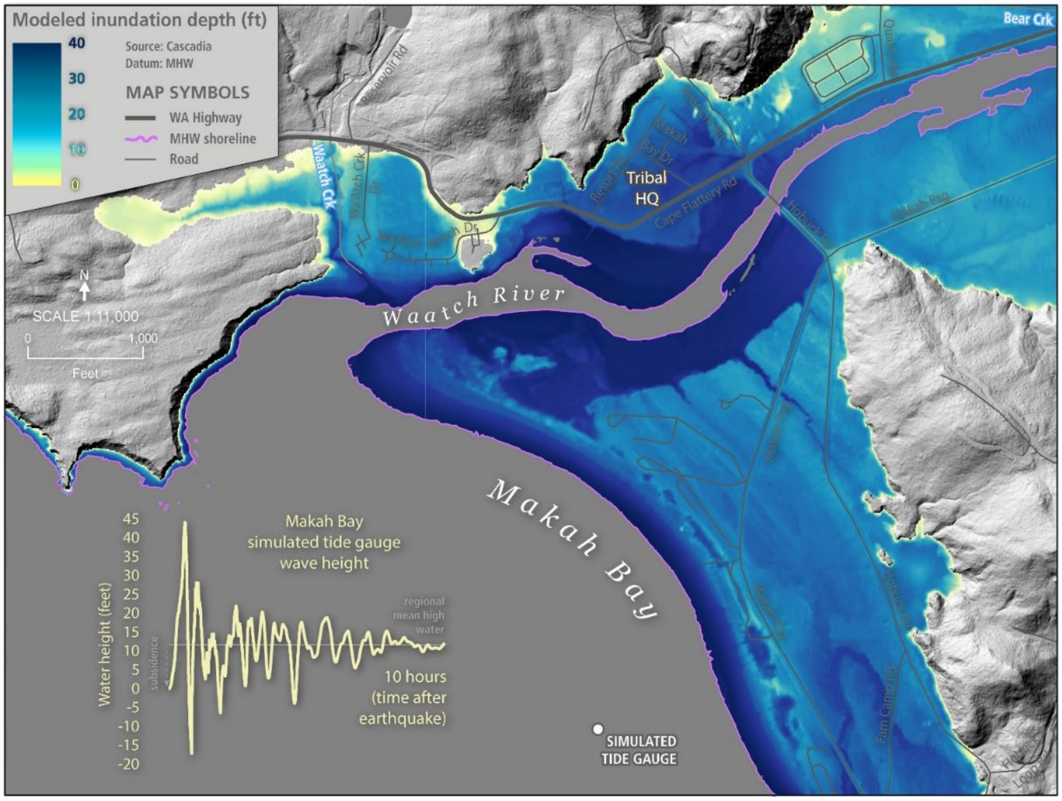

Figure 17: Modeled maximum tsunami inundation depths over land within the Makah Bay boundary area from the Cascadia subduction zone earthquake scenario. Offshore tsunami wave heights within Makah Bay approach 35 feet and onshore flooding depths generally range from 28-33 feet near the Makah Tribal Headquarter facilities. Tidal datum: Mean High Water. Model resolution: 1/9th arc-second (~3 meters).

Coseismic subsidence

Tsunami impacts from the modeled CSZ scenario are also exacerbated due to the potential for land level subsidence, or the sinking of a region of land, during the earthquake shaking. The modeled CSZ earthquake scenario used in this study provides a conservative estimate of regional subsidence and suggests that the land could drop as much as 11-13 feet at the Makah Reservation (Figure 18). Subsidence of this magnitude would have major short- and long-term implications in recovery operations following the tsunami; once the tsunami flood waters recede and drain from the land back to the sea (which may take days), previously dry land and current infrastructure like the Makah Tribal Marina facilities near the shoreline could be lost to the new daily tidal range due to a potentially higher relative sea-level following the earthquake. Additionally, due to already low land elevations within Neah Bay, a large enough subsidence drop from the earthquake may also cut off Cape Flattery from the mainland, essentially forming an island at high tide. It may take decades to centuries for the land level to bounce back to pre-earthquake elevations and many local residents and commercial entities may face relocation challenges.

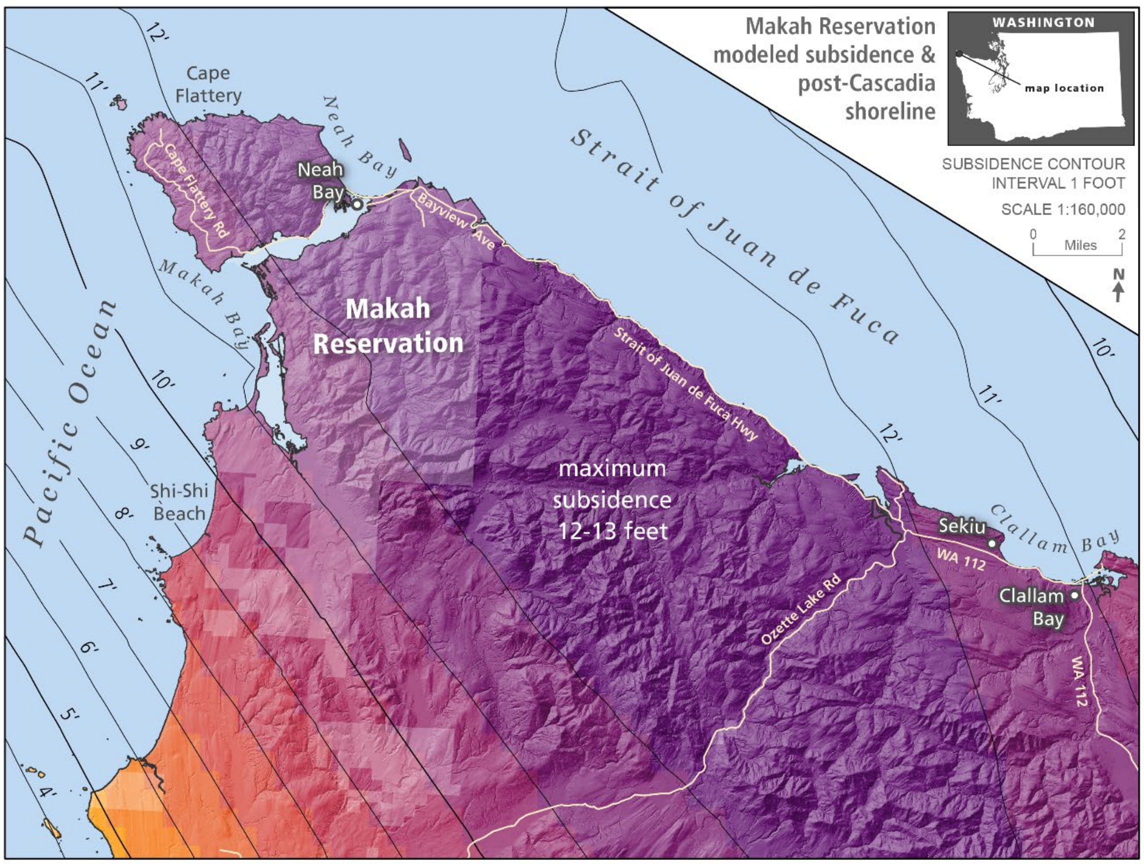

Figure 18: Modeled subsidence and post-Cascadia shoreline for the Makah Reservation. Note subsidence values are considered conservative in the sense that the values are greater than the greatest known paleoseismic subsidence observation recorded on land in Washington, which is ~6 ft (1.76 m) near Cosmopolis (Atwater, 1988; Leonard and others, 2010).

Alaska-Aleutian Subduction Zone

In the modeled Alaska-Aleutian subduction zone (AASZ) scenario, the overall extent of tsunami inundation is much less than what the CSZ scenario projects (Figure 19). In the AASZ scenario, boaters have additional time to make decisions. Boaters out on the water should refer Figure 13 to identify the decision points for whether getting to deep harbor or heading back to land is preferable, keeping in mind that tsunami-related water changes may last up to 48 hours or more after the first wave arrives. The estimated wave heights may still overtop pilings at certain docks, but the inundation is far less than what would be expected in a CSZ scenario within the Makah Marina. On the Makah Bay side, inundation is still expected for large parts of the recreation area, and vessels near the mouth of the Waatch River should keep an eye out for a tsunami bore that would travel upriver. Other tsunami water-level fluctuations, such as grounded vessels from drawdown, are still present and may put vessels at risk for damages.

Flooding on the Neah Bay side of the reservation is limited to only near shoreline locations such as the areas north of Bayview Ave (WA-112; Figure 20). Additionally, modeled offshore tsunami wave heights from this scenario do not exceed 10 feet within the Strait of Juan de Fuca just north of Neah Bay. This suggests that the Waadah Island Jetty would not get overtopped, though it may be possible for water to still breach any weak points.

On the other hand, tsunami inundation is still significant from this distant scenario near Makah Bay. Here, modeled tsunami waves propagate ~3 river miles up the Wa'atch River and flood the majority of Hobuck Beach and many low spots within the prairie, including sections of Makah Passage, Cape Flattery Road, and Hobuck Road (Figure 21). Average flooding depths at these low elevation spots in this river valley range from 1-7 feet, depending on topography. Unlike a local CSZ event, a distant tsunami generated within the AASZ would not cause any subsidence to this study area and the first tsunami waves would not arrive to Makah Bay until ~3 hours and 35 minutes after the earthquake (~3 hours and 40 minutes at the Makah Tribal Marina). This leaves ample time for tsunami response in a similar distant source event.

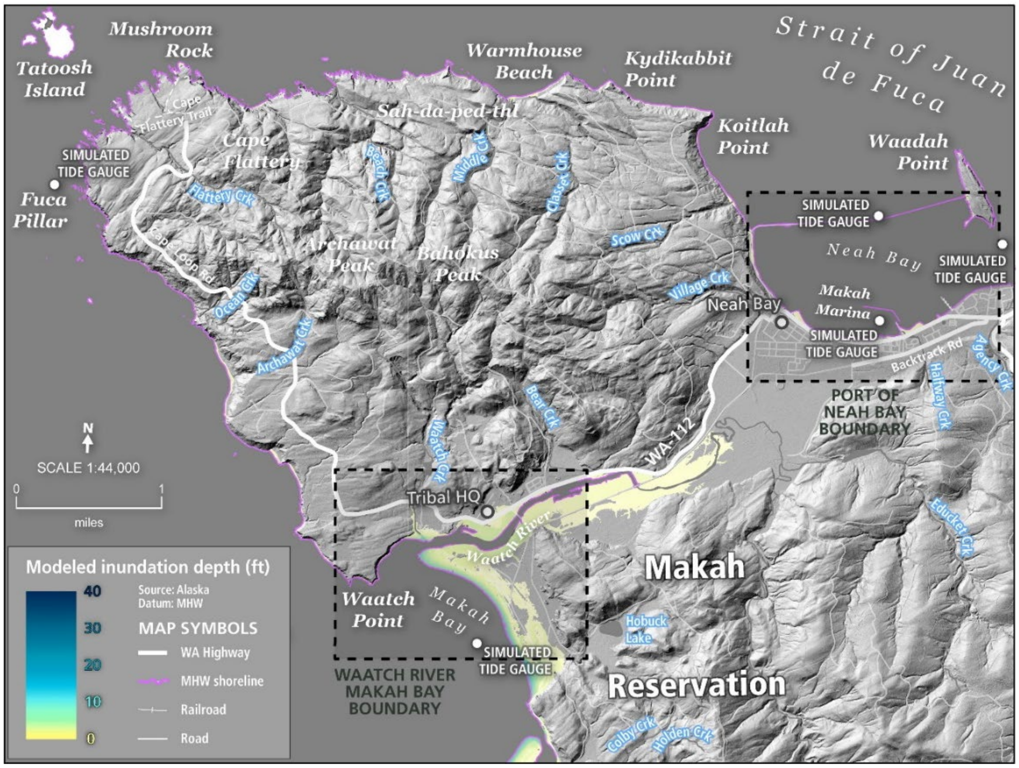

Figure 19: Overview of the maximum modeled tsunami inundation generated by a distant magnitude 9.2 Alaska-Aleutian subduction zone earthquake scenario. Tidal datum: Mean High Water. Model resolution: 1/9th arc-second (~3 meters).

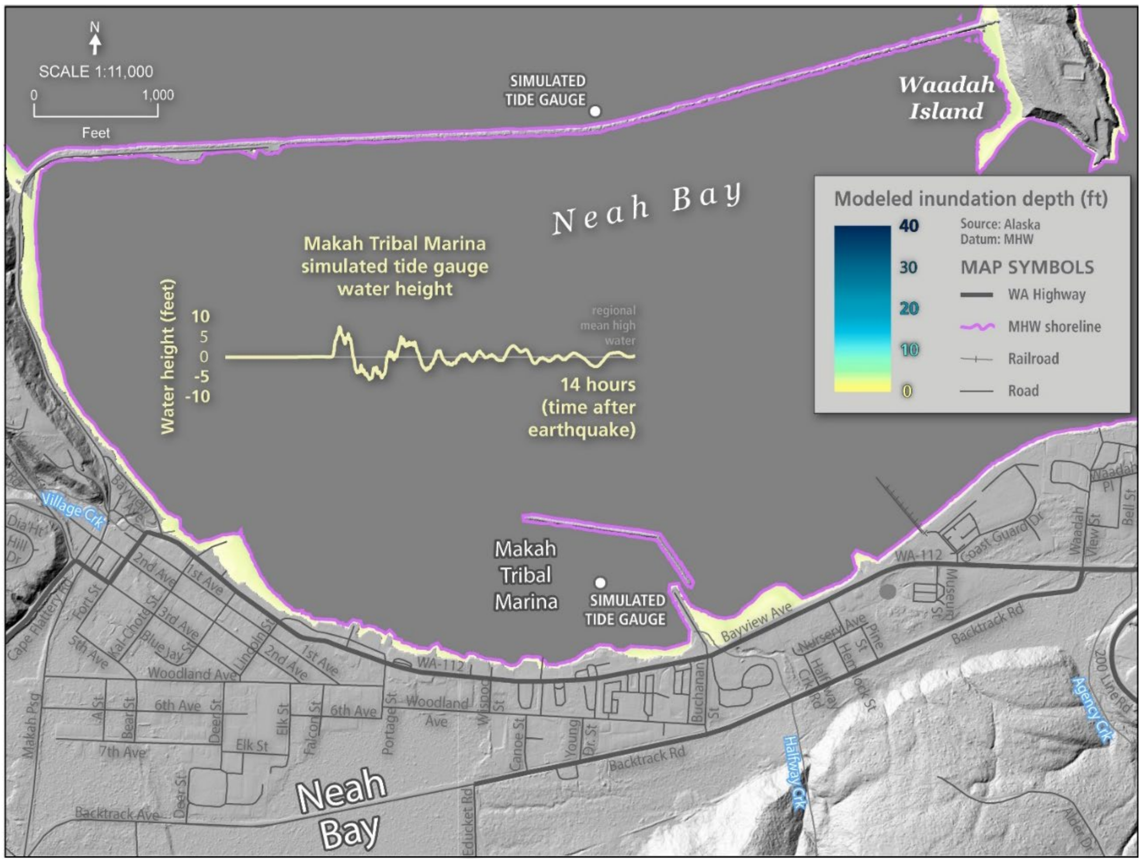

Figure 20: Modeled maximum tsunami inundation depths over land within the Port of Neah Bay boundary area from the Alaska-Aleutian subduction zone earthquake scenario. Offshore tsunami wave heights do not exceed 10 feet and onshore flooding is limited to near shoreline locations. Tidal datum: Mean High Water. Model resolution: 1/9th arc-second (~3 meters).

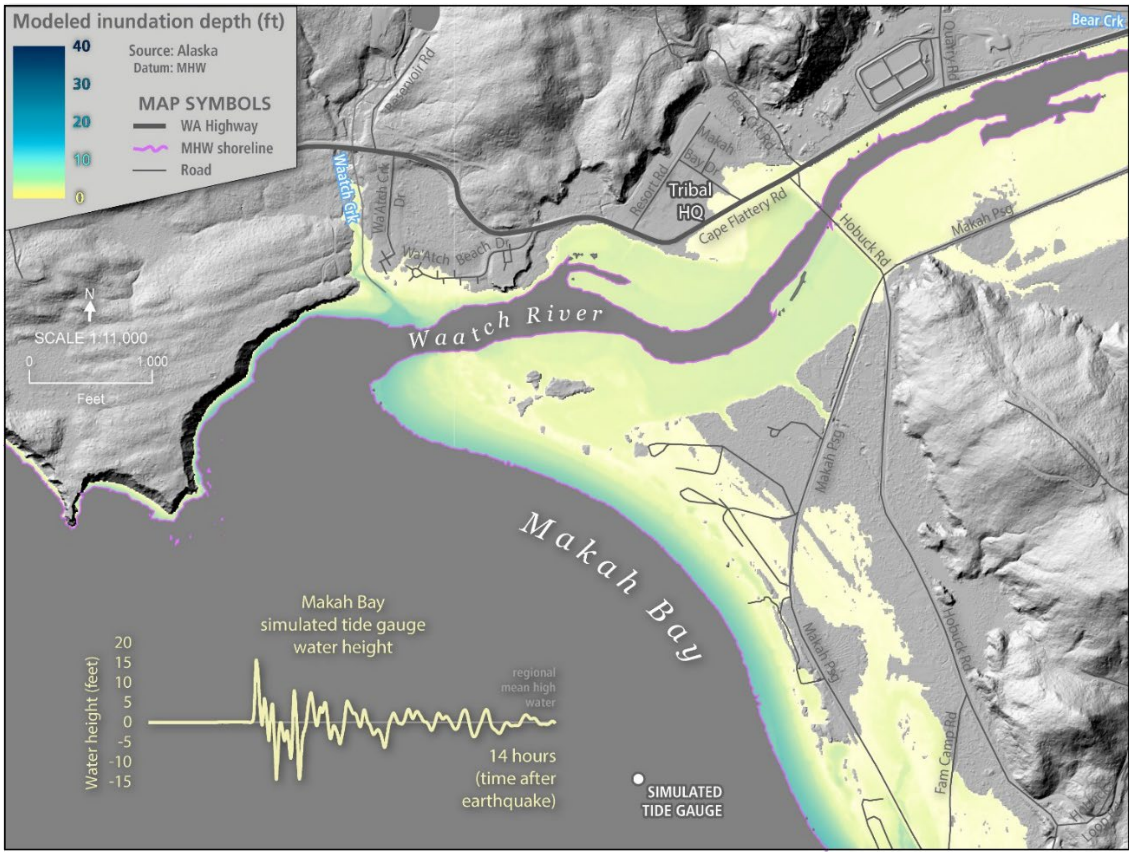

Figure 21. Modeled maximum tsunami inundation depths over land within the Makah Bay boundary area from the Alaska-Aleutian subduction zone earthquake scenario. Offshore tsunami wave heights within Makah Bay approach 16 feet and onshore flooding depths generally range from 1-7 feet, depending on local topography. 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 an 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 were generated on static tides, meaning the current speeds displayed are the result of tsunami forces and are therefore on top of any local current speeds. Normal day-to-day currents should be added to 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, we opted to display current speeds 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 damages (Pat Lynett, 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 when simulating the tsunami at either Mean High Water or Mean Low Water.

It is common for certain topographic or engineered features, like entrances into harbors or marinas, to cause faster nearby currents than the surrounding areas. Additionally, small islands, land spits with narrow passageways, or waterways 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.

Cascadia Subduction Zone

Modeled current speeds from the CSZ scenario locally exceed 9 knots, the maximum categorization, in many areas throughout the study area (Figure 22), including the entrance into Neah Bay (Figure 23), and at the mouth of the Wa’atch River (Figure 24). With current speeds exceeding 9 knots above normal, widespread major damage is expected for the maritime infrastructure and large vessels and may result in complete destruction. As a boat owner, the best course of action is to move inland to high ground immediately after the shaking stops. Waterways will be extremely dangerous for boaters as whirlpools and eddies will create significant challenges in trying to navigate in shallow waters. The large amount of debris from other vessels and maritime infrastructure can create collisions and cause significant damage for other vessels and risk of capsizing.

Speeds are slightly less drastic within the Makah Tribal Marina itself, though are still of strong concern with projected hotspots in the 6-9 knot range. Areas of fastest speeds within the Marina include the stretches closest to shore and around the ends of the breakwaters, including the fish gap entrance on the eastern side. Structures located within these projections could expect major damage, depending on their age, how they were engineered, and how they are maintained.

This scenario also suggests strong current speeds greater than 9 knots along the northwest side of the Pacific coastline, engulfing Cape Flattery's rocky shoreline. These strong currents exist all the way down into Makah Bay, and up the Wa'atch River until flooding eventually combines with the tsunami inundation originating from the Neah Bay side. The model estimates this moment where tsunami currents meet from the northeast and southwest to happen after 30 to 35 minutes from the start of the earthquake shaking.

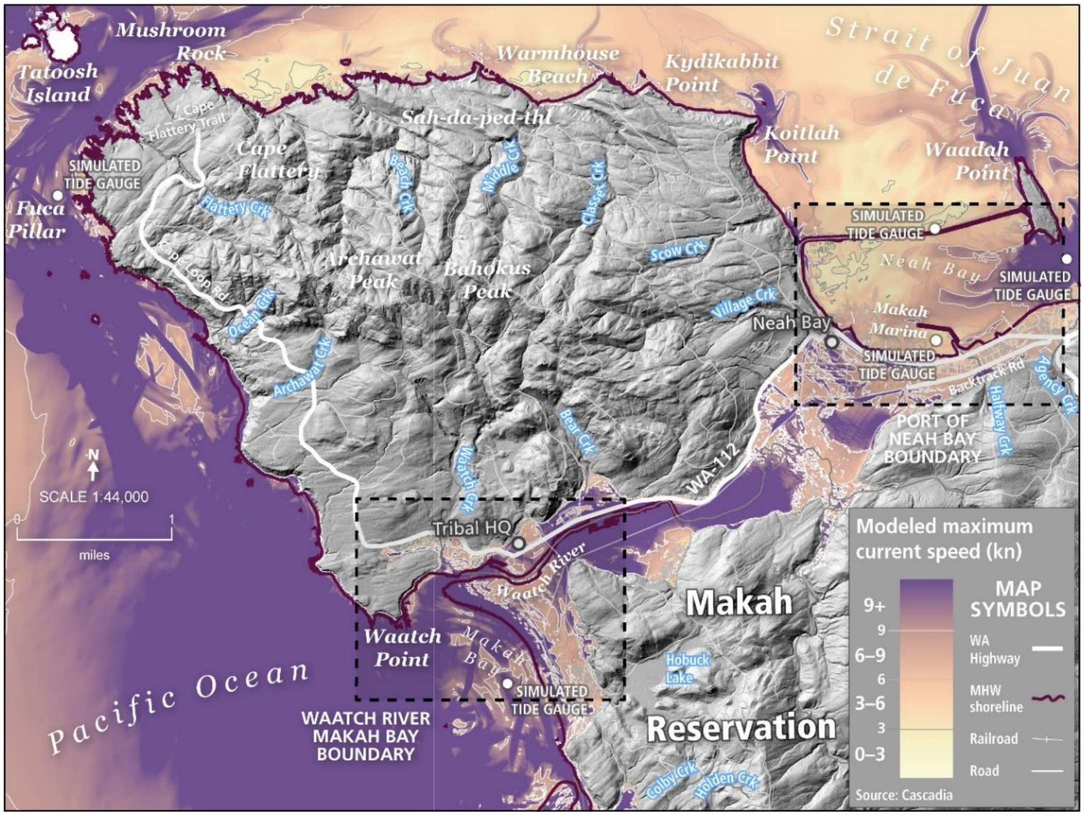

Figure 22: Overview of modeled tsunami current speeds from the Cascadia subduction zone earthquake scenario. Tidal datum: maximum values generated between the Mean High Water and Mean Low Water runs. Model resolution: 1/9th arc-second (3 m).

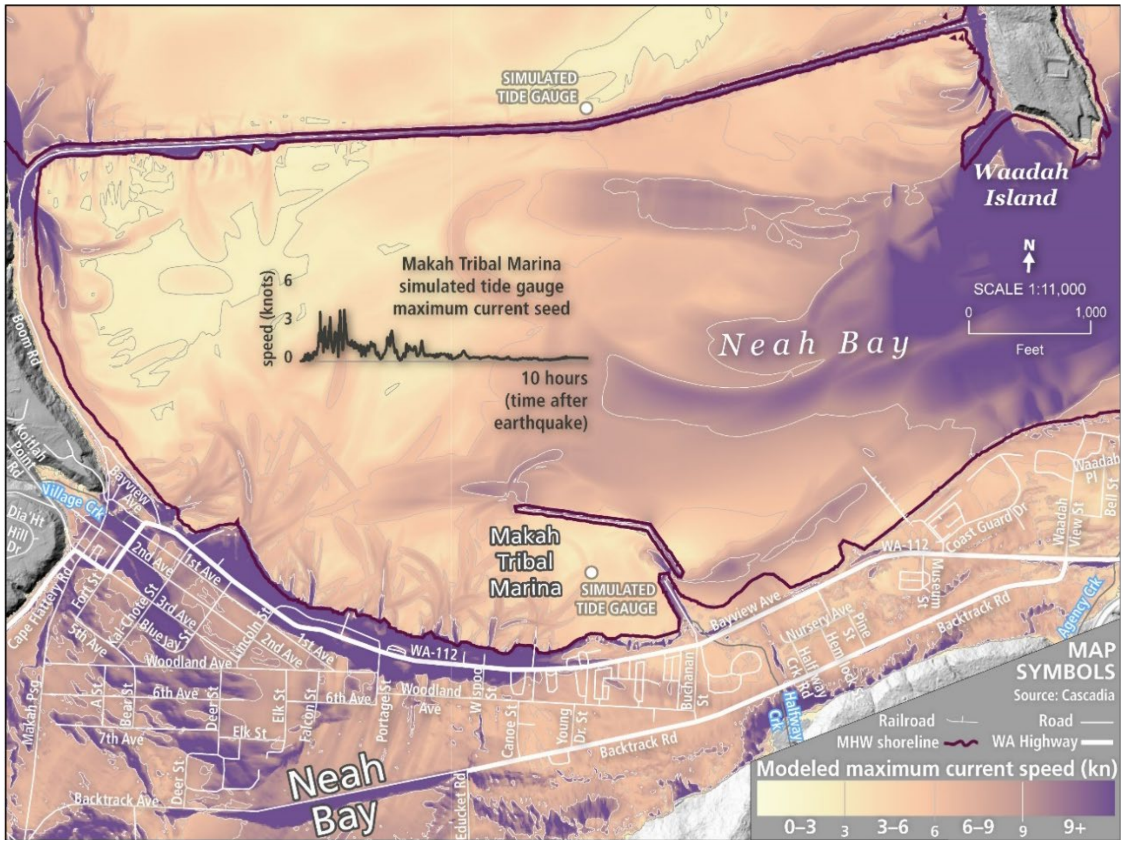

Figure 23: Modeled tsunami current speeds within the Port of Neah Bay boundary area from the Cascadia subduction zone earthquake scenario. Tidal datum: maximum values generated between the Mean High Water and Mean Low Water runs. Model resolution: 1/9th arc-second (3 m).

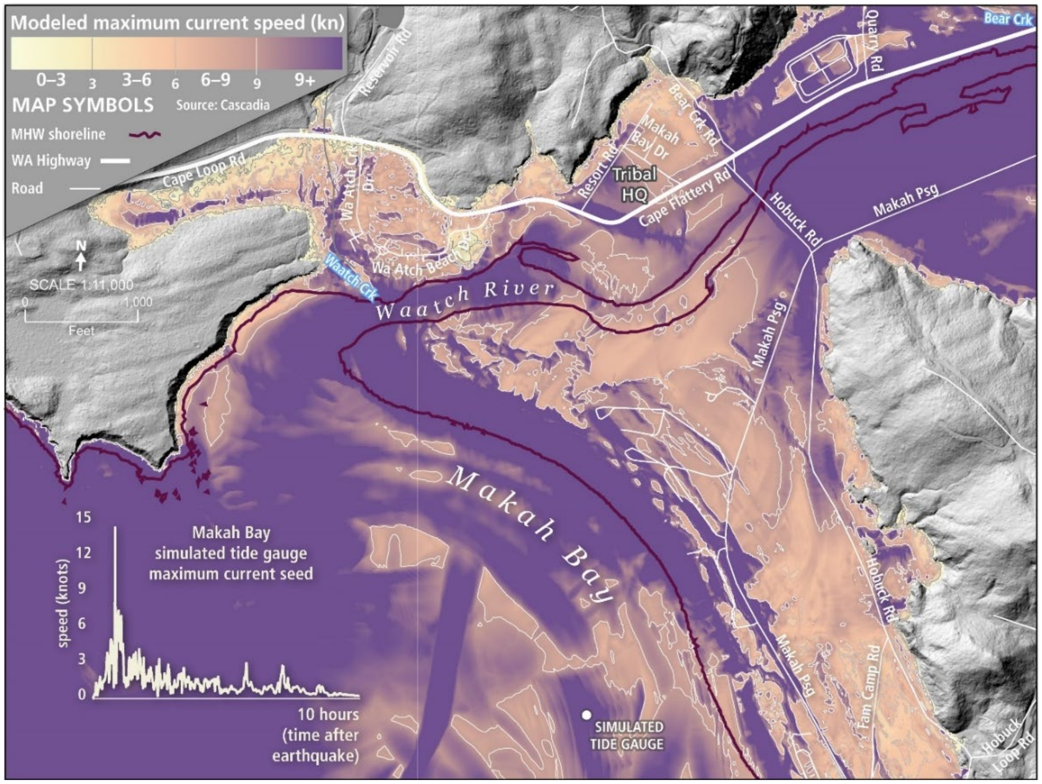

Figure 24: Modeled tsunami current speeds within the Makah Bay boundary area from the Cascadia subduction zone earthquake scenario. Tidal datum: maximum values generated between the Mean High Water and Mean Low Water runs. Model resolution: 1/9th arc-second (3 m).

Alaska-Aleutian Subduction Zone

The modeled Alaska-Aleutian Subduction Zone (AASZ) scenario presents significant risks to infrastructure and boaters, particularly in areas with current speeds ranging from 5-9 knots. These speeds are capable of causing moderate to major damage to docks, piers, and vessels, especially in locations like Waadah Island, the mouth of the Wa'atch River, and just north of Hobuck Bridge (Figure 27). The potential for whirlpools, eddies, and sudden current changes further increases the hazard for boaters, making it highly inadvisable to navigate or remain on the water during these conditions. Collisions with other vessels or debris could result in heavy damage to boats of any size.

At the Makah Tribal Marina, maximum current speeds are generally less than 3 knots, with only two hotspots reaching 4-8 knots, primarily near engineered features such as the breakwater and fish gap entrance (Figure 26). Fastest currents in these areas were often recorded during the trough phase of the tsunami, when water is drawn away from shore, pulling current patterns away from the marina and into the bay. This is observed in both the AASZ and CSZ scenarios (refer to Figures 23 and 25). In contrast, areas with current speeds between 0-3 knots are not expected to experience significant damage, though small objects such as buoys may be displaced.

The AASZ scenario shows relatively milder current speeds compared to the Cascadia Subduction Zone (CSZ) scenario, with select hotspots containing speeds equal to or greater than 9 knots, none of which are within Neah Bay (Figure 25). The modeled offshore wave height entering Neah Bay is not high enough to overtop the jetty, though unknown weak points may allow some fast currents to flow through. The fastest current speeds are maintained for at least the first hour after the tsunami's arrival, making it crucial to avoid these areas.

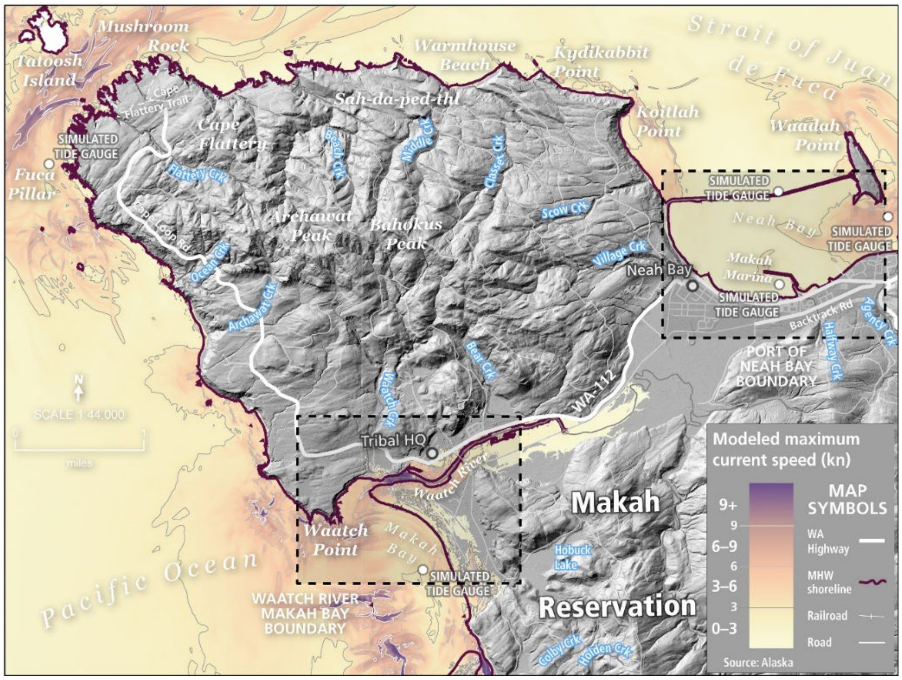

Figure 25: Overview of modeled tsunami current speeds from the Alaska-Aleutian subduction zone earthquake scenario. Tidal datum: maximum values generated between the Mean High Water and Mean Low Water runs. Model resolution: 1/9th arc-second (3 m).

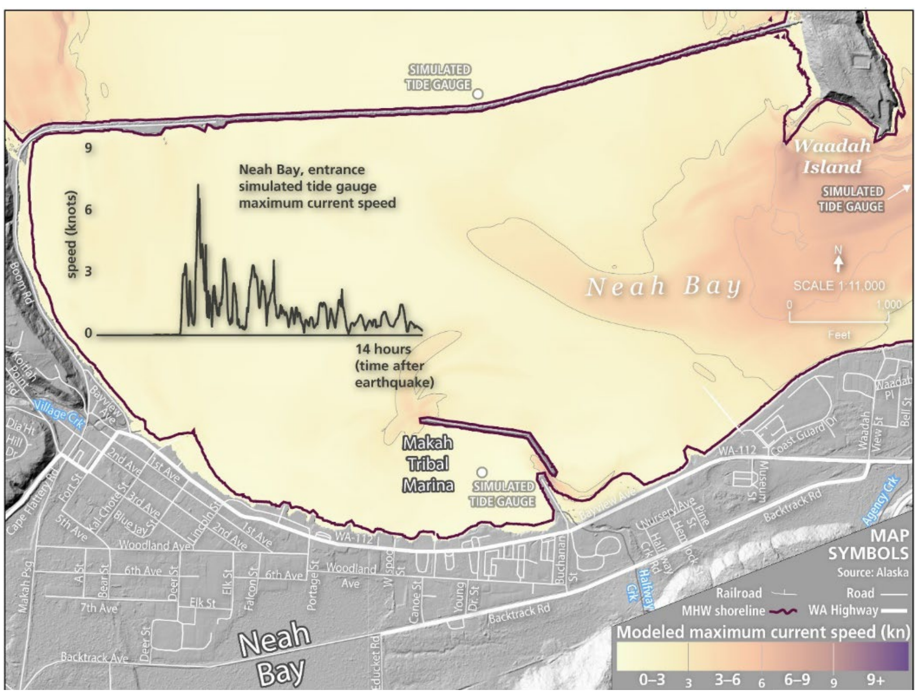

Figure 26: Modeled tsunami current speeds within the Port of Neah Bay boundary area from the Alaskan-Aleutian subduction zone earthquake scenario. Refer to Figure 25 for displayed tide gauge location at the entrance to Neah Bay. Tidal datum: maximum values generated between the Mean High Water and Mean Low Water runs. Model resolution: 1/9th arc-second (3 m).

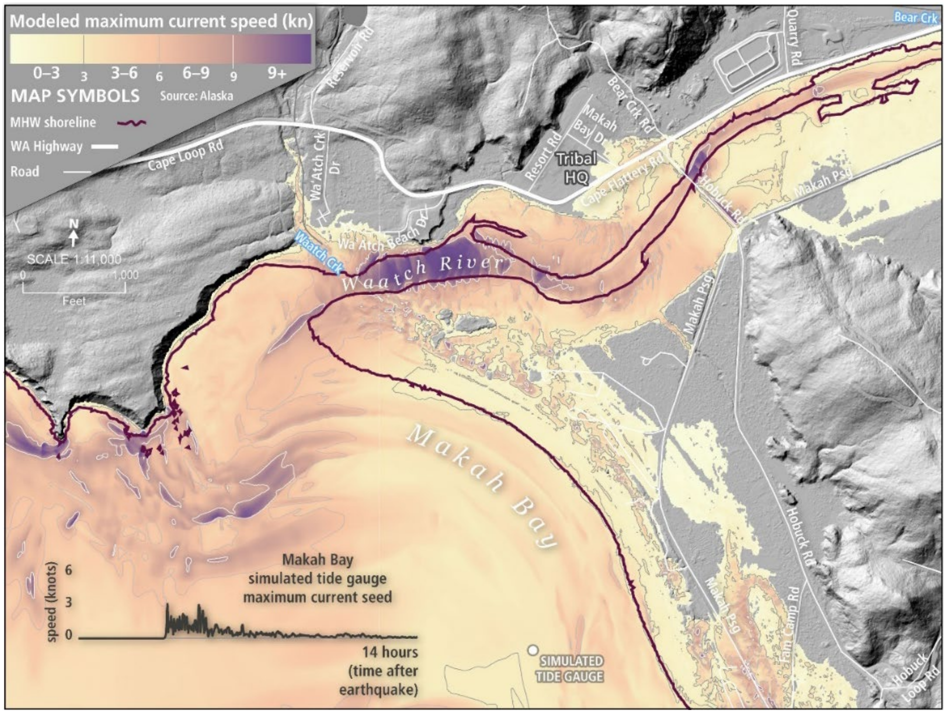

Figure 27: Modeled tsunami current speeds within the Makah Bay boundary area from the Alaskan-Aleutian subduction zone earthquake scenario. Tidal datum: maximum values generated between the Mean High Water and Mean Low Water runs. Model resolution: 1/9th arc-second (3 m).

Minimum Water Depth

The minimum water depths modeled for both the Cascadia Subduction Zone (CSZ) and Alaska-Aleutian Subduction Zone (AASZ) 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.

These minimum water depths provide essential information for assessing where vessels with shorter draft distances should avoid mooring and highlight areas that may need future dredging to reduce the risk of grounding. Figures 28-30 illustrate the CSZ scenario, and Figures 31-33 show the AASZ scenario, all based on low tide conditions for a more conservative estimate.

The drawdown process, which can expose large areas of the seafloor, poses risks of rapid dragging and scouring from sediment shifts, which could cause significant damage to both vessels and infrastructure. Locations particularly vulnerable to these hazards include the Makah Tribal Marina fish gap, the waters near Waadah Island, and the Wa'atch River. To mitigate these risks, dredging shallow areas in the marina and bay could help reduce the potential impact of such extreme drawdown events.

Cascadia Subduction Zone

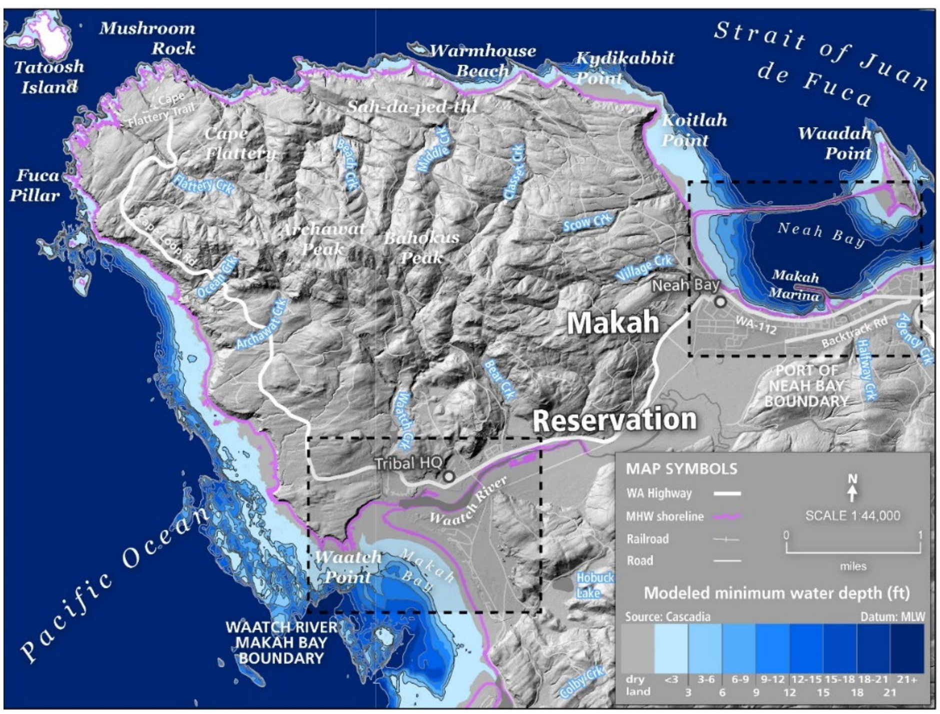

Figure 28: Overview of modeled minimum water depths from the tsunami generated by the Cascadia subduction zone earthquake scenario. Tidal datum: Mean Low Water. Model resolution: 1/9th arc-second (3 m).

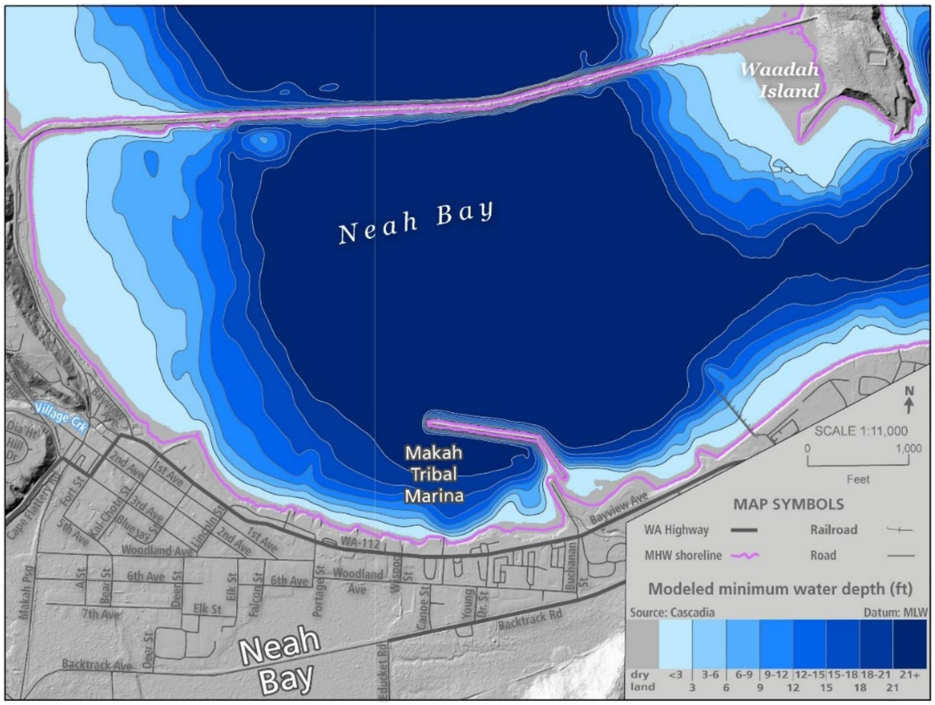

Figure 29: Modeled minimum water depths within the Neah Bay boundary from the tsunami generated by the Cascadia subduction zone earthquake scenario. Tidal datum: Mean Low Water. Model resolution: 1/9th arc-second (3 m).

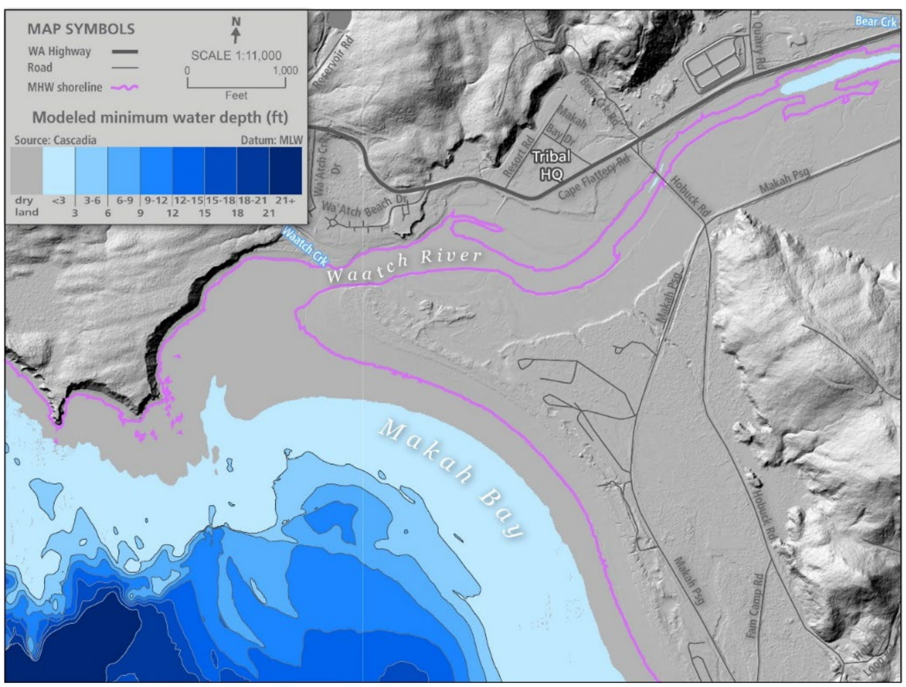

Figure 30: Modeled minimum water depths within the Makah Bay, Wa'atch boundary from the tsunami generated by the Cascadia subduction zone earthquake scenario. Tidal datum: Mean Low Water. Model resolution: 1/9th arc-second (3 m).

Alaska-Aleutian Subduction Zone

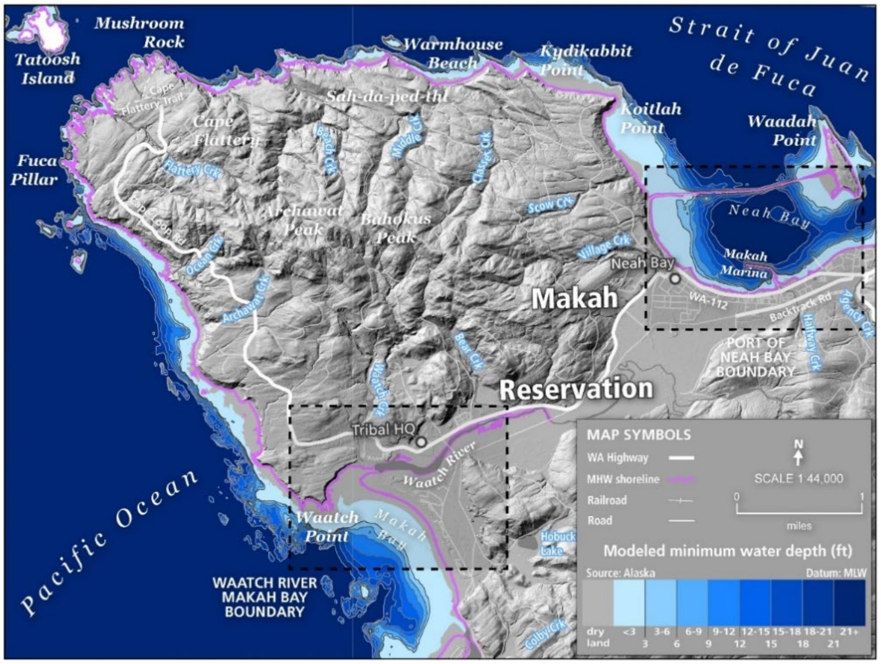

Figure 31: Overview of modeled minimum water depths from the tsunami generated by the Alaska-Aleutian subduction zone earthquake scenario. Tidal datum: Mean Low Water. Model resolution: 1/9th arc-second (3 m).

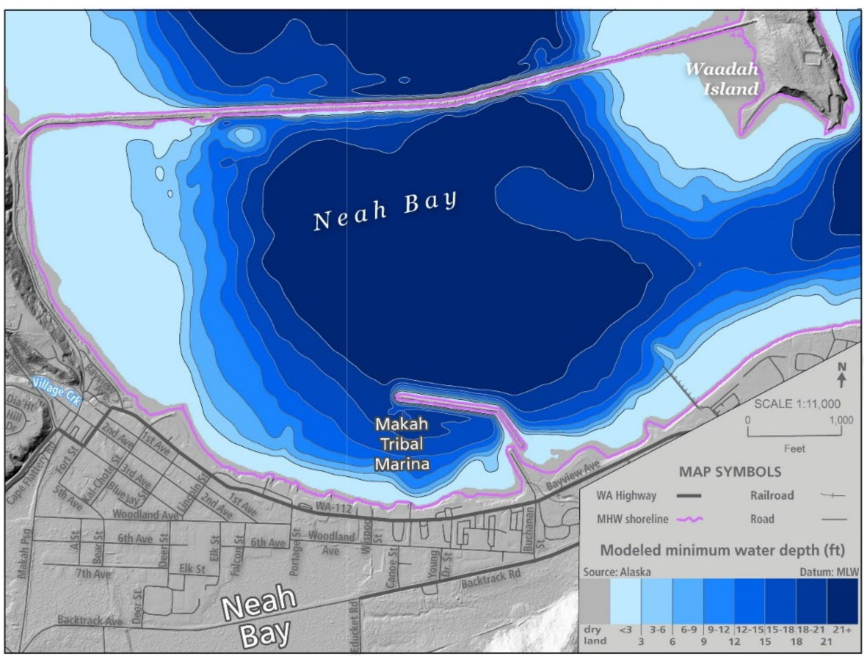

Figure 32: Modeled minimum water depths within the Neah Bay boundary from the tsunami generated by the Alaska-Aleutian subduction zone earthquake scenario. Tidal datum: Mean Low Water. Model resolution: 1/9th arc-second (3 m).

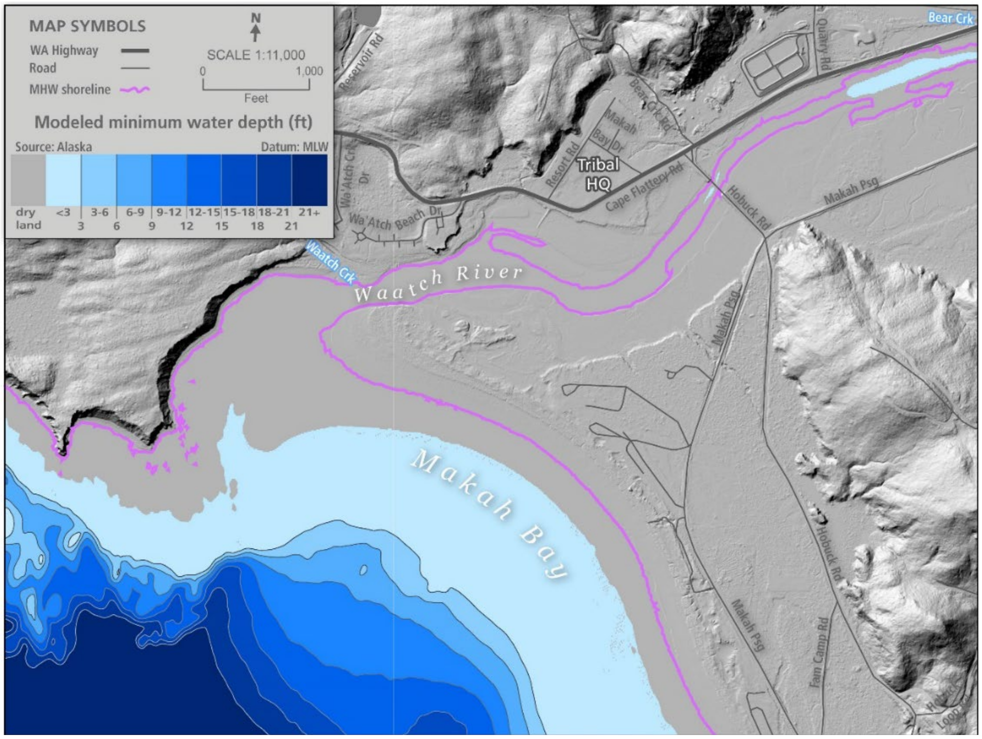

Figure 33: Modeled minimum water depths within the Makah Bay, Wa'atch boundary from the tsunami generated by the Alaska-Aleutian subduction zone earthquake scenario. Tidal datum: Mean Low Water. Model resolution: 1/9th arc-second (3 m).

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 mitigation planning and emergency response, as they provide insights into when and how long maximum wave heights, drawdowns, and fast current speeds may occur during a tsunami. Understanding the timing of these events is critical for developing effective tsunami preparedness and response procedures.

In this study, each synthetic tide gauge records wave heights (Figures 34-36) and current speeds (Figures 37-39) over 10 simulated hours for the Cascadia Subduction Zone (CSZ) scenario and 14 simulated hours for the Alaska-Aleutian Subduction Zone (AASZ) 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 experience larger waves than the models show. Gauges placed in water around 33 feet (10 meters) deep generally provide accurate representations of shoreline wave heights.

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

Makah Bay

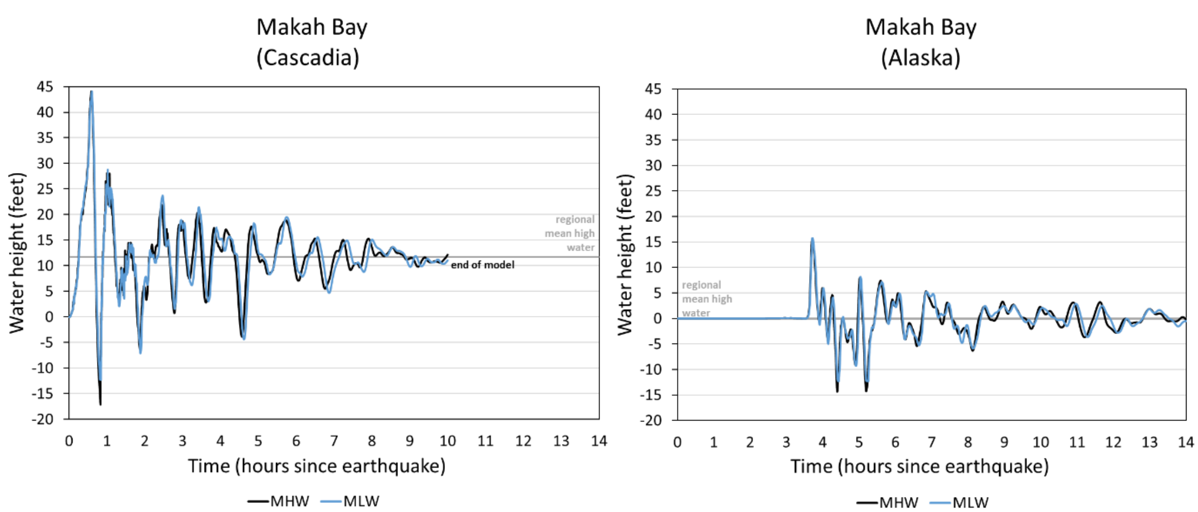

Figure 34: Modeled tsunami wave heights over time at the Makah Bay simulated synthetic tide gauge from the Cascadia subduction zone (left) and Alaska-Aleutian subduction zone (right) earthquake scenarios. Water height '0' represents the post-earthquake elevation, accounting for subsidence in the Cascadia scenario. Black and blue lines represent simulations using either the Mean High Water or Mean Low Water tidal datum, respectively.

Neah Bay, entrance

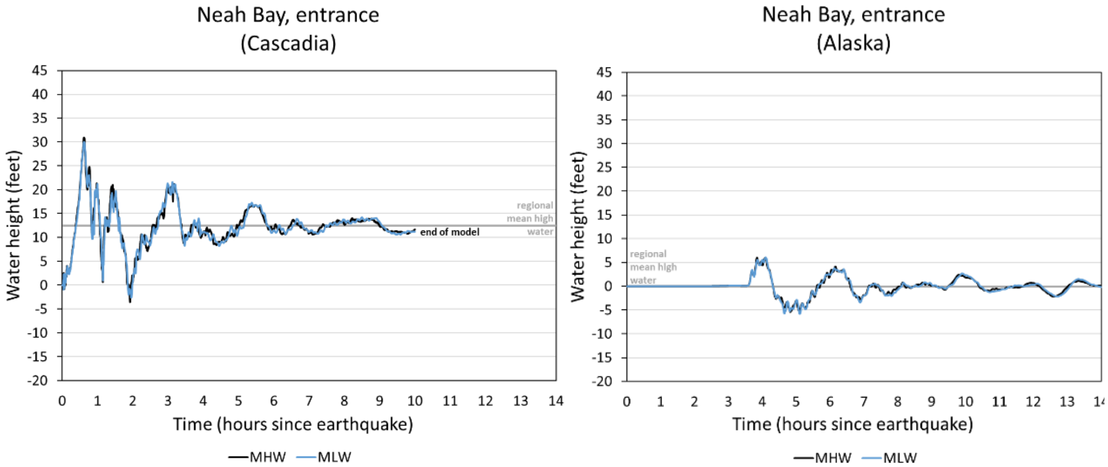

Figure 35: Modeled tsunami wave heights over time at the Neah Bay, entrance simulated synthetic tide gauge from the Cascadia subduction zone (left) and Alaska-Aleutian subduction zone (right) earthquake scenarios. Water height '0' represents the post-earthquake elevation, accounting for subsidence in the Cascadia scenario. Black and blue lines represent simulations using either the Mean High Water or Mean Low Water tidal datum, respectively.

Makah Tribal Marina

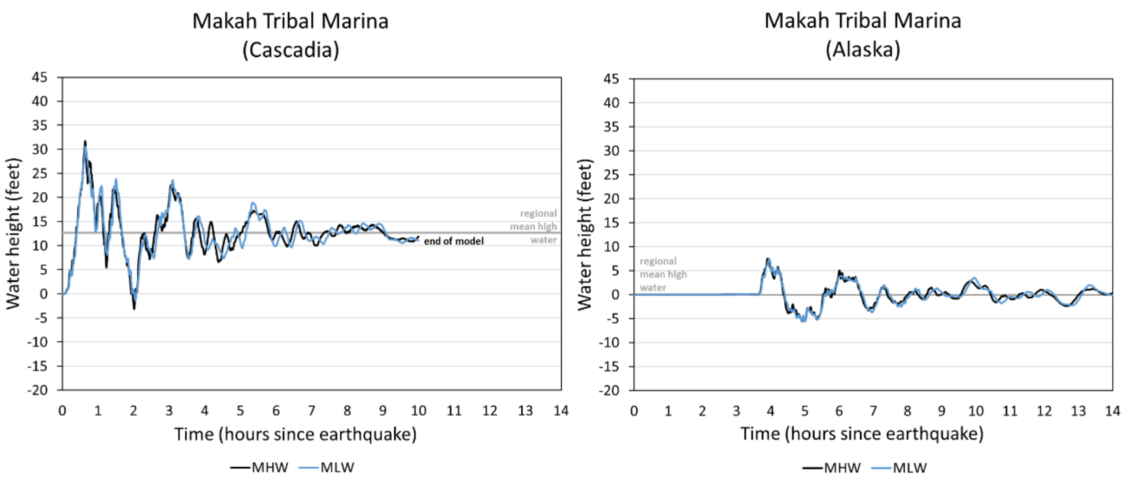

Figure 36: Modeled tsunami wave heights over time at the Makah Tribal Marina simulated synthetic tide gauge from the Cascadia subduction zone (left) and Alaska-Aleutian subduction zone (right) earthquake scenarios. Water height '0' represents the post-earthquake elevation, accounting for subsidence in the Cascadia scenario. Black and blue lines represent simulations using either the Mean High Water or Mean Low Water tidal datum, respectively.

Wave Current Speeds through Time

Makah Bay

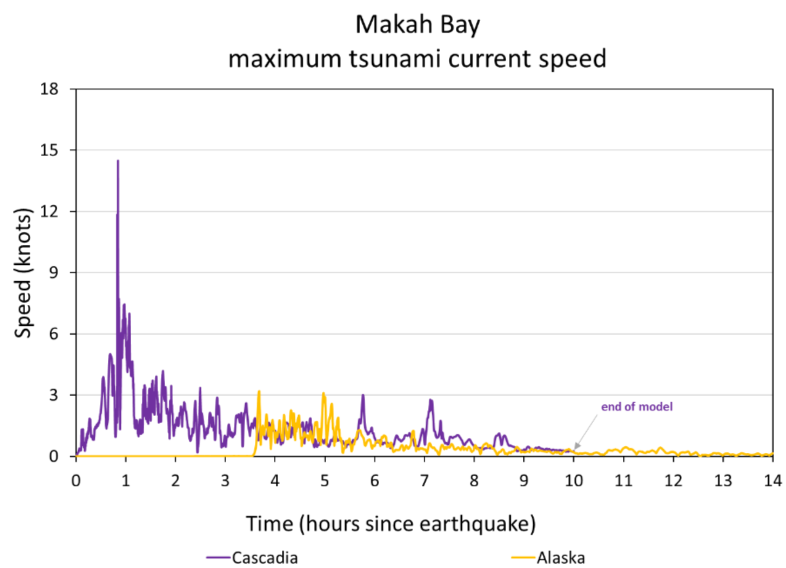

Figure 37: Modeled tsunami current speed over time at the Makah Bay simulated synthetic tide gauge. Purple and yellow lines represent simulations from the Cascadia and Alaska-Aleutian subduction zone earthquake scenarios, respectively. Reported speeds are maximum values generated from either the mean high water or mean low water simulations.

Neah Bay, entrance

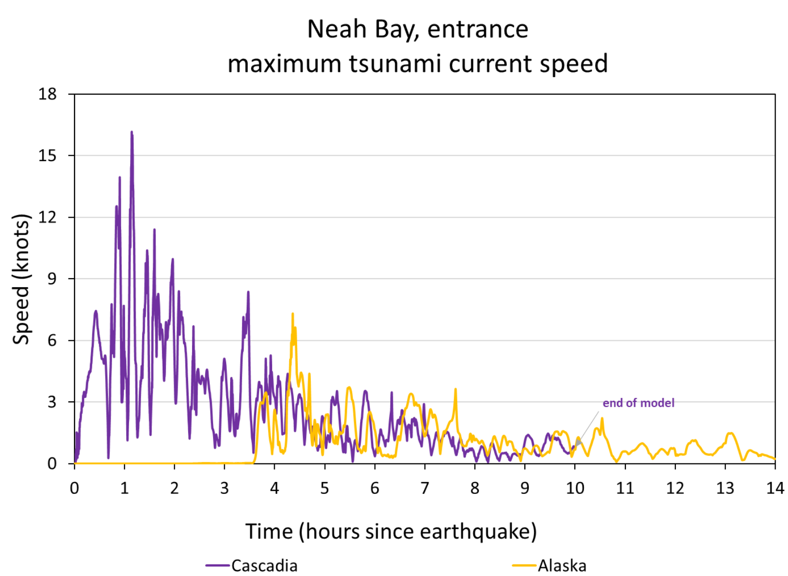

Figure 38: Modeled tsunami current speed over time at the Neah Bay, entrance simulated synthetic tide gauge. Purple and yellow lines represent simulations from the Cascadia and Alaska-Aleutian subduction zone earthquake scenarios, respectively. Reported speeds are maximum values generated from either the mean high water or mean low water simulations.

Makah Tribal Marina

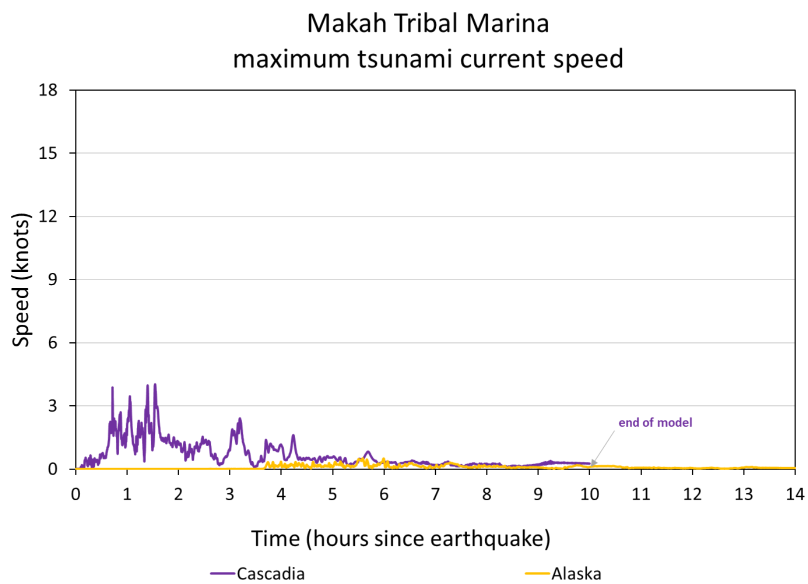

Figure 39: Modeled tsunami current speed over time at the Makah Tribal Marina simulated synthetic tide gauge. Purple and yellow lines represent simulations from the Cascadia and Alaska-Aleutian subduction zone earthquake scenarios, respectively. Reported speeds are maximum values generated from either 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 event 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 warning 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 are also 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 event. Like TMax, this might not correspond to the first wave

Cascadia Subduction Zone (CSZ)

Table 1 shows a summary of approximate tsunami wave arrival times, in minutes, using different wave height thresholds from the Cascadia subduction zone earthquake scenario. Note that coseismic subsidence at time 0 causes the land and sea surface elevation to drop simultaneously. Following this drop, the sea-surface begins to rebound back to the regional pre-earthquake conditions, independent of tsunami impacts. Reported times do not differentiate water height fluctuations driven by subsidence recovery versus tsunami.

Cascadia scenario, timing since start of earthquake					
Location	**TFirst Advis**	**TFirst Draw**	**TFirst Warn**	**TMax**	**TMin**
Makah Bay	4	44	7	35	50
Neah Bay, entrance	1	114	7	37	115
Makah Tribal Marina	8	119	11	38	121

Alaskan Aleutian Subduction Zone (AASZ)

Table 2 shows a summary of tsunami wave arrival times, in minutes, using different wave height thresholds from the Alaska-Aleutian subduction zone earthquake scenario.

Alaska scenario, timing since start of earthquake					
Location	**TFirst Advis**	**TFirst Draw**	**TFirst Warn**	**TMax**	**TMin**
Makah Bay	217	245	218	222	264
Neah Bay, entrance	218	261	221	231	290
Makah Tribal Marina	222	265	224	234	295

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.

This section details such tsunami responses strategies, details the reason to implement them in emergency planning, and expands on their specific feasibility to be implemented for the Port of Neah Bay.

Tsunami Response Actions

Below we provide 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.

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, clearly labeled, and able to be shut off remotely can save time and improve likelihood of success.

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.

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.

Informing and Coordinating with Key First Responders During a Tsunami

Local first responders play a key role in alerting, evacuation, 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.

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 dangerous health 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 will not be enough time to do so during most local source tsunamis.

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 should always be preferred.

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.

For ports and marinas that lie on the coast of the open ocean, relative safety for vessels can be found at depths of 30 fathoms (180 feet) for a distant source tsunami and 100 fathoms (600 feet) for a local source tsunami. In some locations the distance to these depths is short and, depending on the time it will take for the first wave to arrive, evacuation of vessels to sufficient depths may be possible. The evacuation effort must be planned, orderly, and controlled to avoid dangers associated with congestion in the waters. Some jurisdictions, such as the Island of Oahu in the state of Hawaii, have already implemented such plans.

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. 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 in 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.

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.

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 cause additional damage. 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.

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.

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

A major part of the post-tsunami response will be the rescue, survey, and salvage operations in the area. 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. Whatever is not salvageable will need to be removed.

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 properly and securely moored. Given the size of some harbors and number of slips and vessels to check, it is not possible to check the entire area and every vessel 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.

Remove Small Vessels from the Water

Tsunamis can generate an extensive amount of debris which can damage vessels and other marine assets due to fluctuating current speeds, inundation, and drawdown. Prior to tsunami wave arrival, ports and marinas may be able to remove their 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 would also be a time-consuming and labor-intensive process which would require 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 would need to be provided for port staff and its users would need to be informed of those 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.

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. 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 moderately secured buoyant assets, they may remain secured during a smaller distant source tsunami.

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 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.

Feasibility of Tsunami Response Guidance for the Port of Neah Bay and Makah Tribe

In the comprehensive evaluation of tsunami response actions for the Port of Neah Bay and the Makah Tribe, each potential action was evaluated based on its feasibility, classifying them as either 'Feasible,' 'Needs Review,' or 'Not Feasible.' This critical analysis takes into account the unique characteristics and vulnerabilities of the Port of Neah Bay and the Makah Tribe. The applicability of these response actions extends to scenarios involving both a Cascadia Subduction Zone (CSZ) and an Alaskan-Aleutian Subduction Zone (AASZ) 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 of Neah Bay and the Makah Tribe. 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 of Neah Bay and the Makah Tribe in the face of potential seismic events from both the Cascadia and Alaskan-Aleutian Subduction Zones.

Tsunami Response Actions	Feasibility for Port of Neah Bay
Identify Boat Owners/Individuals Who Live Aboard Vessels and Establish Notification Processes	**Feasible**
Shut Down Port Infrastructure Before Tsunami Arrives	**Feasible**
Evacuate Public/Vehicles from Waterfront Areas	**Feasible**
Personal Floatation Devices for Port Staff	**Feasible**
Informing and Coordinating with Key First Responders During a Tsunami	**Feasible**
Remove or Secure Hazardous Materials Used or Owned by Port	**Needs Review**
Move Vessels Out of the Port	**Needs Review**
Restrict Traffic Entering the Port by Land and Aid in Traffic Evacuation	**Needs Review**
Activate Incident Command at Evacuation Sites	**Needs Review**
Activate Mutual Aid System as Necessary	**Needs Review**
Pre-stage Emergency Equipment Outside Affected Area	**Needs Review**
Pre-Identify Personnel to Assist in Rescue, Survey and Salvage Efforts	**Needs Review**

Secure Moorings of Port Owned Vessels	**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**

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

Feasibility for the Port of Neah Bay: Feasible

Makah Emergency Management should collaborate closely with the Port of Neah Bay to enhance communication and alert systems for boat owners, particularly those using liveaboard moorage at the Marina. Previous experiences during Alaska events demonstrated that informing known liveaboards about tsunami alerts by going door to door was effective. Building on this, there is a strategic opportunity to incorporate updated information on signing up for tsunami alerts, receiving Regroup alerts from the Tribe, and accessing educational resources about tsunamis into the Port of Neah Bay's Moorage agreements.

These updated moorage agreements can significantly enhance education and awareness about tsunami risks in water and nearshore areas. To ensure this information reaches all relevant stakeholders, the Tsunami Alert List, including both WA EMD and Regroup Tribal Alerts, should be reviewed and updated. Alert communications should be disseminated through multiple channels such as SMS, email, apps, and NOAA radios, ensuring redundancy in case of technology or infrastructure failure. A comprehensive tracking system should be created to monitor recipients and identify who is responsible for managing and updating the alert lists. This system will streamline the dissemination process, ensuring timely alerts and enhancing overall preparedness.

In tandem, there is a need for the Port of Neah Bay to revise moorage agreements to address concerns such as abandoned vessels and to update moorage rates. Close collaboration between the Port, WA EMD, and Port Authority will be necessary to ensure these changes align with both economic and emergency preparedness objectives. Additionally, CERT members should be leveraged to support emergency management (EM) capacity building and community education initiatives. CERT members can assist with outreach efforts related to alert sign-ups, evacuation practice, and wayfinding.

Regular education and outreach initiatives should be conducted to increase public awareness and preparedness. By partnering with WA EMD and Clallam County Emergency Management, opportunities to build local capacity and provide targeted training can be identified. These efforts will ensure that the community is well-informed on how to receive alerts, what the alerts mean, and what protective actions to take. Empowering the community with this knowledge will enhance the resilience of both the Makah Tribe and the Port of Neah Bay, ensuring that tribal members, boat owners, and residents are prepared to act swiftly and effectively during emergencies.

Through these combined efforts, updating moorage agreements, improving communication channels, and leveraging CERT teams for outreach and capacity-building, the Tribe can strengthen emergency preparedness and ensure a coordinated, community-wide response to future tsunami threats.

Shut Down Port Infrastructure Before Tsunami Arrives

Feasibility for The Port of Neah Bay: Feasible

Although there are no currently outlined standard operating procedures (SOPs) to shut down Port infrastructure, it is feasible for the Port to turn power, water, and fuel lines off once a tsunami alert has been received. Shutting down Port infrastructure upon receiving a tsunami alert appears achievable, although specifics regarding procedures need expansion from the Port of Neah Bay. Directives for such actions typically stem from the Tribal Council, with crucial decision-making input from the Tribal General Manager on behalf of the tribal community. Communication channels primarily involve direct phone calls, with the Tribal General Manager playing a central role in executing Council directives, often through convened meetings at specified locations within set timeframes.

The capability to shut off fuel and power sources exists, but the absence of documented procedures necessitates further clarification. Similarly, taking lessons learned locally in oil response may prove beneficial for more robust tsunami response planning. Defining protocols for shutting off a large propane tank outside the conference room and potentially the Mini Mart could be beneficial as well. Effective communication channels and response protocols are pivotal for a coordinated response, warranting collaboration with Makah Emergency Management and Tribal Council to establish clear communication channels and response procedures.

Evacuate Public/Vehicles from Waterfront Areas

Feasibility for the Port of Neah Bay: Feasible

Once the Makah Tribe and the Port of Neah Bay are alerted to a tsunami threat, Makah Emergency Management and public safety personnel will take immediate steps to disseminate information and mobilize response efforts. The message about the tsunami alert will be transmitted to responders and it is possible to disseminate it to the whole community (but whole community written emergency alert response procedures are not yet defined). Although most responders have police scanner radios, an emergency broadcast tone going off over radio is typically reserved for EMS, police, or fire department emergencies, rather than tsunami warnings, which are unlikely to be broadcasted over the scanner.

Efforts will be made to refine the Regroup alert notification process, ensuring that specific messages are directed to the appropriate groups needing to receive them. The Health Center/Clinic already has written Standard Operating Procedures (SOPs) in place for various scenarios, including local and distant tsunamis. However, there is a need to update and ensure that all tribal departments have updated procedures in place. While the Tribe has a hard copy of a Tsunami Emergency Evacuation Plan, it is not readily available due to an ongoing move of supplies between buildings and there is not a digital copy. Makah Emergency Management emphasized the importance and need to digitize and update the Comprehensive Emergency Management Plan (CEMP) to reflect current procedures and protocols, including the Tsunami Emergency Evacuation Plan for the Tribe.

During a tsunami, Makah Emergency Management and Public Safety personnel will collaborate closely, with Makah Emergency Management overseeing response operations and Public Safety ensuring road blockades, safety measures, and efficient evacuation from the tsunami inundation zone. The Makah Police Department will manage the activation of All Hazard Alert Broadcast (AHAB) tsunami sirens manually if necessary, ensuring that the community is alerted promptly. It is recommended that the Tribe does an assessment of who can manually activate the sirens, what alerts the sirens would be activated for (including other hazards outside tsunami), and that personnel have the adequate training to use them. There is interest from the Tribe to also test manual activation of the sirens periodically to ensure personnel are properly trained and familiar with how the sirens operate in case they do need to be manually activated.

Makah Emergency Management aims to establish points of contact and alternate points of contact at evacuation check-in points, facilitating efficient communication and coordination during evacuation drills and real time tsunami response. The Tribe will also be responsible for making the decision to allow members of the public to return to impacted areas post-tsunami and should outline these procedures and decision points. In addition to manned evacuation points, there are unmanned evacuation trails maintained by the Makah Chamber of Commerce and other entities, providing alternative routes for evacuation. Coordination efforts will involve meetings with stakeholders, including hatcheries, to ensure that evacuation plans are comprehensive and address potential inundation risks adequately. Overall, the goal is to enhance communication, coordination, and preparedness within the Makah Tribe and the Port of Neah Bay community during a tsunami.

Personal Floatation Devices/Vests for Port Staff

Feasibility for the Port of Neah Bay: Feasible

The Port of Neah Bay aims to enhance its water safety measures beyond just providing personal flotation jackets to staff and crew. There is a desire to procure additional life rings and strategically stage them along each pier and other accessible locations for both Port and beach users. The intention is to make them easily visible and accessible in case of emergencies. Most recreational boaters already tend to wear personal flotation devices, potentially contributing to overall safety awareness in the area.

Informing and Coordinating with Key First Responders During a Tsunami

Feasibility for the Port of Neah Bay: Feasible

In the context of the Port of Neah Bay and the Makah Tribe, regardless of whether a tsunami impacting the area is local or distant, multiple local agencies and stakeholders will be involved from the outset in protective actions, response, and recovery efforts. Currently, there are no documented SOPs for the Port or the Tribe to communicate their status or needs to EMS and the Fire and Police Departments. However, most responders have police scanner radios, receiving notifications through a tone-out system. Although there is no specific protocol for disseminating a tsunami alert over the scanner, breaking down the Regroup alert system process into separate lists could streamline communication efforts. A review of the Regroup lists would be recommended to ensure that the appropriate responders and decision-makers are receiving alerts for not only tsunamis, but other alerts as well. The Sophie Trettevick Indian Health Clinic (STIHC) manages this list and can work closely with Makah Emergency Management to review and update the list routinely.

Moreover, while the STIHC has written SOPs for various scenarios, including local and distant tsunamis, it is uncertain if other Tribal departments have updated procedures. The Comprehensive Emergency Management Plan (CEMP) exists along with the Tsunami Evacuation Plan but requires updating. Efforts are underway to improve communication infrastructure, such as exploring emergency cell phone programs and utilizing satellite phones. Currently, the Tribe has multiple satellite phones, a police radio in the EOC, and MedNet to communicate with hospitals. There is also an ongoing discussion about having Starlink set up to support the EOC and the Port, but funding would need to be identified. It is recommended that the Tribe utilize the STIHC's written SOPs to standardize and develop SOPs across all tribal departments and agencies. Following the development of documented SOPs, the Tribe can work with the WA EMD tsunami program to review SOPs and provide subject matter expertise as needed.

Communication between the Makah Tribe and Clallam County Emergency Management is excellent regarding previous emergency response activities and needs overall. In terms of tsunami response communication, the Tribe deems it essential for the Clallam County Department of Emergency Management to establish clear lines of communication with the Port and the Tribe. This could involve utilizing VHF radios and coordinating with other agencies overseeing critical infrastructure to ensure accurate information exchange during emergencies. Additionally, the implementation of local conference calls, like those in Grays Harbor County, could enhance communication and collaboration among responders and essential stakeholders during tsunamis and is of high interest from the Makah tribe. This could happen with Clallam County leading a focused tsunami coordination call during response and provides an opportunity for more intrinsic collaboration and builds capacity at the local and tribal level.

In addition to communicating with first responders, having an established local conference call would be helpful for safety managers of each tribal department to attend. They would be able to share specific needs and give updates that would facilitate tsunami response actions within the tribe and to Clallam County EM. Other than establishing a local conference call, Makah Emergency Management wants to prioritize meeting with Safety managers in the Tribe to ensure safety managers know their roles and responsibilities along with who they are communicating with during tsunami response. Makah Emergency Management would like to also make sure each department has a tsunami response plan that is updated that includes primary points of contact, roles and responsibilities and special considerations that need to be taken for each department.

Activate Incident Command at Evacuation Sites

Feasibility for the Port of Neah Bay: Feasible

While the current Makah Emergency Operations Center (EOC) is housed at the Makah Marina administrative offices, plans are in place to move the primary EOC to the new Emergency Management Office (EMO) building, which is located outside the tsunami inundation zone. Given its strategic location outside the risk area, activating Incident Command from this site is highly feasible, provided the proper equipment and resources are in place.

To ensure the new EOC is fully operational, the Tribe will need to get new equipment for this location is regularly updated and inventoried with necessary supplies, including communication equipment, satellite phones, radios, and response coordination tools. This will ensure the EOC can function effectively in the event of a tsunami or other emergency.

In addition to upgrading the EOC's physical infrastructure, it is equally important to focus on training and leadership development for key personnel involved in incident command. The Incident Command System (ICS) plays a crucial role in emergency response, and collaboration with FEMA to address specific training needs will be instrumental in strengthening the Tribe's preparedness. FEMA offers customized training programs through their Emergency Management Institute (EMI), which includes a specialized Tribal Curriculum designed for tribal governments. This curriculum, delivered by experienced instructors with a background in tribal emergency management, provides targeted training in critical areas such as incident command, emergency response coordination, resource management, and communication protocols.

Key stakeholders, including Tribal Council members, department heads, and emergency management staff, should participate in these training initiatives to ensure they are equipped with the skills needed to effectively manage an emergency. These leadership training programs can be tailored to the unique requirements of the Makah Tribe, helping to build the capacity of those responsible for incident command. Specific training in resource management and emergency communication protocols will allow leaders to respond more cohesively during crises, while coordination exercises will help them apply ICS principles in real-world scenarios.

By enhancing both the physical capabilities of the EOC and the leadership skills of key personnel through FEMA's training programs, the Makah Tribe will be better prepared to activate Incident Command and respond efficiently to emergencies, ensuring both operational continuity and community safety. This curriculum includes a comprehensive six-course track designed specifically for tribal governments. For more details, visit https://training.fema.gov/tribal/.

Remove or Secure Hazardous Materials Used or Owned by Port

Feasibility for the Port of Neah Bay: Needs Review

The Tribe should consider updating emergency response plans with the Port of Neah Bay and Business Enterprises to incorporate procedures for securing Tribe-controlled or managed chemical and waste storage areas in and around the Port, especially in light of the unstable fuel dock at the Port. The fuel dock, managed by Business Enterprises but not owned by the Tribe, poses a significant risk during tsunamis as it could lead to fuel spills into Neah Bay. There have been past incidents of instability, including a vessel sinking that had to be cut loose due to concerns about the dock's structural integrity. Given its susceptibility to damage during tsunami events, exploring options like automatic shutoffs or developing SOPs to shut off fuel lines in emergencies is highly recommended. This proactive approach would mitigate the risk of environmental contamination in the event of a tsunami and ensure the safety of the Port and surrounding areas. Additionally, ongoing outreach efforts with users, boaters, and tenants should include information on personal response actions to secure hazardous materials and prevent potential spills during emergencies.

Move Vessels Out of the Port

Feasibility for the Port of Neah Bay: Needs Review

There are several areas of concern when it comes to this recommendation. Additionally, modeled maximum current speeds may exceed >9 knots above normal around the Port of Neah Bay during both CSZ and Alaska tsunami scenarios, creating dangerous conditions for vessels to navigate.

Second, the Port does not have any authority to instruct boat owners to take any specific actions related to leaving their vessels docked or taking them out on the water during a tsunami. While first responders may be evacuating coastal areas, many boat owners may try to reach their vessels to take them out to deep water offshore instead of leaving them docked. In addition, the Port and other surrounding private companies may at the same time be attempting to take their very large vessels out to the open ocean, especially in the distant AASZ M9.2 scenario in which there may be several hours to react prior to wave arrival.

To determine if this process could safely take place, additional study and review is necessary. The Port of Neah Bay would have to coordinate with other local, state, and federal agencies to determine feasibility of staging areas for both commercial and recreational vessels. WA EMD can facilitate conversations with the U.S. Coast Guard to benefit not only the Port of Neah Bay but other ports, harbors, and marinas in Washington as well. This coordination would be essential since the Port does not have the authority to handle vessels or require vessels to move during a tsunami.

Considering that large boats typically head out to sea with at least three hours of warning, collaboration among stakeholders and clear communication channels are paramount for effective tsunami response in Neah Bay. It is crucial to ensure that plans are not only established but also documented and regularly reviewed to uphold readiness and coordination during emergency situations.

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

Feasibility for the Port of Neah Bay: Needs Review

Restricting traffic from entering the Port by land and aiding in land traffic evacuation is not feasible for a Cascadia Subduction Zone (CSZ) scenario due to the short window of wave arrival, typically around 15 to 20 minutes after the earthquake. However, in the case of an Alaska-Aleutian Subduction Zone (AASZ) scenario, there is a 3+ hour window for estimated wave arrival, making evacuation efforts and traffic control more achievable. Despite this extended time frame, evacuations should not be delayed or postponed. The notice to evacuate must be issued immediately after receiving a tsunami warning to account for variables such as traffic conditions, weather, or unforeseen delays.

Responsibility for evacuating people from the waterfront areas falls primarily under the Makah Tribal Police rather than the Port of Neah Bay. It is recommended that the Tribe develop a communication strategy to send immediate alerts to evacuees, directing them to leave vessels and move to high ground. At that point, evacuees will come under the jurisdiction of the Makah Tribal Police for further guidance. The Tribe should also review current plans and coordinate with other tribal agencies to create a more comprehensive evacuation strategy that addresses traffic, both pedestrian and vehicular, in shoreline areas.

Currently, there is no established process for restricting traffic from entering the Port during a tsunami evacuation. This gap highlights the need for a formal plan, including designated tasks for Port staff to assist the Tribal Police in restricting access and managing evacuation traffic. Coordination with the Makah Tribal Police is essential to establish clear roles, communication protocols, and processes for assisting with the evacuation.

Additionally, education for Port personnel, tenants, and users is critical. They must understand how they will receive communications from Makah Tribal Emergency Management during emergencies, including tsunami evacuations. To reinforce this, the Port should implement regular tsunami evacuation drills and training sessions, ensuring that personnel are familiar with their roles and the procedures they need to follow. These drills should incorporate realistic wave arrival times and focus on immediate response actions following tsunami warnings, particularly those for the AASZ scenario, where there is a longer window for evacuation.

To further enhance preparedness, the Tribe and the Port should regularly participate in exercises and drills like those facilitated by the WA EMD Tsunami Exercises and the NTWC Pacifex Exercise. These exercises provide an opportunity to evaluate and strengthen communication systems, identify gaps, and refine evacuation protocols. By using a strategic, phased approach, drills can increase in complexity over time, building the Tribe's capacity to handle larger-scale evacuations. This progressive training process ensures continuous testing and improvement, helping to address current gaps while setting long-term goals for enhancing the overall resilience of the community during tsunami events.

Activate Mutual Aid System as Necessary

Feasibility for the Port of Neah Bay: Needs Review

Incorporating mutual aid into emergency response efforts requires both comprehensive documentation and standardized communication protocols for coordination between the Makah Tribe and external agencies. Currently, the Tribe has an established mutual aid agreement with the Clallam County Public Utility District (PUD), but it is recommended to explore, document, and review all existing mutual aid agreements to better support emergency operations, including during tsunami events. This documentation is critical for ensuring clarity and consistency, particularly as new personnel join the team, as institutional knowledge may not always be sufficient.

By documenting and standardizing communication protocols for both internal coordination and external collaboration with mutual aid partners, the Makah Tribe can create more streamlined and effective interactions during emergencies. These standardized procedures will help reduce reliance on informal practices and ensure continuity during critical moments.

Training staff on how mutual aid systems work, what agreements are in place, and how to activate them during tsunami response is essential. FEMA Incident Command System (ICS) training for Tribal Council members, department heads, and emergency management staff can further reinforce these protocols, ensuring that all parties involved are well-prepared to request and implement mutual aid effectively during crises. This will align internal tribal efforts with external support systems, ensuring a cohesive and coordinated response when needed.

Pre-Stage Emergency Equipment Outside Affected Area

Feasibility for the Port of Neah Bay: Needs Review

The current Makah Emergency Operations Center (EOC) is housed at the Makah Marina administrative offices, equipped with communication and radio resources essential for emergency response. Although the EOC is not situated within the modeled inundation zone for a AASZ scenario, its location presents a significant risk during a CSZ tsunami and earthquake. Recent conveniences have led to EOC meetings being held at the Makah Marina; however, it is strongly recommended to reconsider relocating the primary EOC location to the new Emergency Management Office (EMO) building outside the inundation zone and not at the Makah Marina.

When the EMO building is complete, Makah Emergency Management should conduct a proper assessment and inventory of EOC supporting assets, including printers, laptops, satellite phones, and baseline radio and communications equipment. In previous activations, such as the most recent oil spill response, some printers and laptops did not work properly, causing delays in overall response and coordination and highlighting the need for reliable equipment. Having not only a base EOC kit that is properly updated and inventoried but also a mobile EOC would ensure redundancy and support relocation or provide additional support to another location, such as the Sail River Heights apartment complex's conference room (previously used for wildfire response). A Starlink system should be situated with this mobile EOC and can also serve as the EMO's primary Starlink device.

Various trailers, including a laundry trailer, shower trailer, and Red Cross trailer stocked with supplies, Connex containers, and storage facilities, house a range of emergency resources like cots, tents, and supplies outside the inundation zone for both CSZ and AASZ scenarios. Maintaining proper inventory management and conducting periodic inventories are crucial to ensure the readiness and availability of these resources during emergencies. While supplies are available at these sites, an updated inventory management system for these emergency supplies and assets is highly recommended and has been identified as a priority need by Makah Emergency Management for support. Conducting a comprehensive inventory of all emergency supplies and assets is a valuable recommendation and has sparked interest among other partners in the Seabrook, WA community, presenting a potential opportunity for collaboration.

In addition to these resources, the Makah Tribe possesses various emergency response assets, including police boats, two jet skis (one under repair), an all-terrain vehicle, and oil spill response trailers near the marina. Due to their crucial role in water-related emergencies, it is advised not to relocate these assets away from the Marina. The Fire Department and EMTs have access to a drone and a trained pilot for aerial surveillance, which is currently stored two city blocks away from the marina. If feasible, relocating this asset outside the modeled inundation zone of Cascadia could prove beneficial in assisting damage surveillance and response efforts post-Cascadia Earthquake and Tsunami. It's also important to regularly ensure emergency assets, like the drone, radios, shower trailers, and laundry trailers, are working properly, updated, and receive regular maintenance as needed for use in emergency response situations. Collaboration and coordination among all stakeholders are crucial to enhancing emergency response capabilities and ensuring effective utilization of available resources.

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

Feasibility for the Port of Neah Bay: Needs Review

Port staff lack the expertise to conduct extensive damage assessments or provide guidance on reopening facilities post-tsunami. Consulting a maritime construction company or an engineering firm is crucial to ensure a thorough assessment of Port facilities. In the aftermath of a local tsunami, the primary focus will be on search and rescue efforts due to the expected widespread and catastrophic damage not only to the Port of Neah Bay but also to the entire Tribe's infrastructure.

The USCG Station Neah Bay will deploy rescue boats offshore, including two 47s and one 29, and will return to assist with search and rescue operations after the tsunami has subsided. Their area of operations spans about 50 miles, and some vessels can get closer to the shore for rescues instead of relying solely on helicopter assistance. The USCG 13th District office will oversee operations beyond their local capabilities and seek additional resources as needed, highlighting the importance of coordination between the Tribe, USCG Station Neah Bay, USCG District 13, and WA EMD for effective response and assistance.

The Makah tribe recently initiated a Community Emergency Response Team (CERT) program, offering standardized training and organization for volunteers in emergency management response support. This program could significantly contribute to supporting first responders in rescue, survey, and salvage operations, particularly since federal and local assistance may take time to arrive following a Cascadia tsunami in Neah Bay. Collaboration among CERT groups, local private companies, and tribal members is crucial for a coordinated and effective emergency response.

Secure Moorings of Tribal Owned Vessels

Feasibility for the Port of Neah Bay: Needs Review

Collaborating closely with Makah Emergency Management, the Port of Neah Bay is urged to incorporate specific tsunami response messaging into their communications with Marina users, especially regarding the mooring of vessels at the Marina. While it may not be feasible for the Port to secure all moorings, they can provide protective action recommendations to private vessel owners. These recommendations should be customized based on expected wave arrival times to prioritize life safety and should align with evacuation efforts from waterfront areas and can be communicated on the Regroup alert system.

Makah Emergency Management, along with the Port of Neah Bay and WA EMD, can collaborate to review and develop scenario-specific messages for alert dissemination among Tribal members, particularly marina users. Additionally, the Port should emphasize the importance of proper mooring in public education materials and other communications to ensure Port users comprehend the significance of securing their vessels during tsunami events. WA EMD will continue working with the Port to provide tsunami response recommendations for boaters including the distribution of the Tsunami Boater's Guide to their users.

During workshops, it was observed that the tribe oversees a fleet of boats, each with its captain. Furthermore, some individuals may own their boats, and the tribe compensates them for various activities like dinners and fishing. Past experiences have demonstrated that when tsunami alerts are issued, owners and the Port have adhered to their plans accordingly. Makah Emergency Management is interested in what written procedures exist for the various boats and whether organizations like Marine Spill Response Corporation (MSRC) have their own plans in place. A review of these plans and procedures in the community would be beneficial as the Port and Makah Emergency Management are updating their own plans and procedures for tsunami response.

Reposition Ships Within the Port

Feasibility for the Port of Neah Bay: Not Feasible

While there is a potential window of 3+ hours for wave arrival for AASZ, repositioning ships within the Port is not a recommended measure. With the breakwater on the northern side of Neah Bay and around Makah Marina, wave action would be diminished by the time they arrive within Makah Marina. Prioritization should focus on the proper moorage vessels and evacuating people from the Marina and away from the shoreline.

Additionally, the Port does not have the authority to handle privately owned vessels or require them to move during a tsunami. Makah Tribal Emergency Management and the Port should communicate with vessel operators and provide instructions and guidance as necessary in accordance with U.S. Coast Guard recommendations and communications via the Vessel Traffic Service. On the state level, WA EMD should work closely with the U.S. Coast Guard to have a better understanding of tsunami response actions region wide that could help all ports, harbors, and marinas in Washington in their own response plans. The Port of Neah Bay should include protective action guidance and procedures in their emergency response plans to communicate with vessel operators and ensure that proper training and exercising is provided for that communication.

Remove Small Vessels from the Water

Feasibility for the Port of Neah Bay: Not Feasible

The Marina has a single boat launch that can be closed to the public during emergencies to ensure limited access and prioritize public safety. However, the primary focus should be on directing both the public and Port personnel to higher ground rather than removing port-owned vessels from the water. It is crucial to prioritize moorage for Port and Tribally owned vessels that can be utilized in tsunami response efforts, but only for a distant tsunami as there is not enough time to do so for a Cascadia tsunami.

In line with other recommended response measures outlined in this strategy, the Port can play a vital role in educating vessel owners about recommended protective actions during tsunamis. This includes securing their moorage effectively and moving inland to higher ground to ensure the safety of themselves, their crew, and their vessels. This proactive approach can significantly enhance overall preparedness and response capabilities during tsunamis.

Remove Buoyant Assets Out of and Away from the Water

Feasibility for the Port of Neah Bay: Not Feasible

It is important to note that removing buoyant assets from the water is not advisable. Instead, the primary focus should be on directing both the public and Port personnel to higher ground during tsunami events. This approach prioritizes life safety over the removal of Port-owned buoyant assets from the water.

Aligned with other recommended response measures in this strategy, the Port can contribute significantly by educating vessel owners about protective actions during tsunamis. This includes securing their own buoyant assets and relocating to higher ground to ensure the safety of themselves, their crew, and their vessels. This proactive approach not only enhances preparedness and response capabilities during tsunamis but also helps minimize the risk of dislodged buoyant assets becoming potential debris.

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

Feasibility for the Port of Neah Bay: Not feasible

The US Coast Guard can restrict the entrance of recreational traffic into or out of the Port, which they do for hazardous bar conditions. More coordination between the Port of Neah Bay and the Coast Guard in addition to WA EMD and the Coast Guard is recommended to clarify roles, responsibilities, and response actions.

The Port can recommend vessel owners take certain protective actions depending on their location and wave arrival time, but they cannot specifically require certain actions to be taken. Instead, the Port will work with WA EMD to provide these recommendations through a combination of ongoing public education and outreach initiatives to inform boaters of protective actions to take during tsunamis and better understand how to protect themselves and their crew. Coordinating with WA EMD, the Port could also investigate disseminating information (signs, published materials, and online/social media) to inform users where to go for information such as Coast Guard Marine Broadcasts, NWS Radio, etc., during a tsunami.

Section 5: Tsunami Maritime Mitigation Funding and Support

Tsunami mitigation efforts require significant resources, and securing funding is critical to ensuring resilient infrastructure and prepared communities. 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 in terms of a multi-hazard approach that addresses other coastal hazards, such as sea level rise driven by climate change, king tides, storm surge flooding, and erosion. These hazards, though distinct from tsunamis, can significantly impact coastal infrastructure and community resilience. 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.

Some programs, such as those offered by 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 tools and approaches represent a comprehensive, yet not exhaustive, list of options to potentially fund some of these mitigation measures. You will likely utilize several funding options throughout the course of your project.

Potential Mitigation Funding Sources

1. RCO Grant (Recreation Conservation Office)

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 the BRIC program, Flood Mitigation Assistance (FMA), and the Hazard Mitigation Grant Program (HMGP). These programs support projects that mitigate hazards such as floods, tsunamis, and earthquakes. All grants require a local match. Upon receiving a grant, the community has three years to complete the work. All grants are awarded on a competitive basis. Jurisdictions must have a FEMA-approved Hazard Mitigation Plan (HMP) to be eligible. Projects funded by federal grants will require an environmental and historic preservation review.

- **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.
- **Application Period**: Annual cycle for different HMA programs, with deadlines typically in the fall.

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. BRIC Grant (Building Resilient Infrastructure and Communities)

The Building Resilient Infrastructure and Communities (BRIC) program, managed by FEMA, is a hazard mitigation grant focused on pre-disaster hazard mitigation projects that strengthen infrastructure resilience against natural disasters. This grant encourages innovative, large-scale infrastructure projects that reduce risk and build resilience against hazards like floods, earthquakes, tsunamis, and more. This is a nationally competitive grant opportunity. The program is available annually to eligible entities such as states, state agencies, federally recognized tribes, and local jurisdictions for the purpose of mitigation planning initiatives and hazard mitigation projects. WA EMD administers and oversees this program for the state of Washington, including the application process for all eligible entities. (Federally recognized Tribes, however, may apply directly to FEMA.)

- **Eligibility**: States, local governments, territories, tribes, and private nonprofits with FEMA-approved hazard mitigation plans.
- **Matching Requirements**: 25% match, with potential reductions for eligible small or economically disadvantaged communities.
- **Funding Range**: Typically, grants can be substantial, with a maximum funding cap of $50 million for large infrastructure projects.
- **Application Period**: Annual cycle, with the submission deadline usually in late fall.

To learn more about BRIC 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.

4. PIDP Grant (Port Infrastructure Development Program)

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. Rebuilding American Infrastructure with Sustainability and Equity (RAISE)

The Rebuilding American Infrastructure with Sustainability and Equity (RAISE) 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 RAISE grants outlined. For more information about specific matching requirements, please contact raisegrants@dot.gov.
- **Funding Range**: The program has been funded at $1.5 billion annually, with grants supporting a wide range of project sizes. A total of $7.2 billion has been awarded since the program's inception. Previous awards have ranged from $3 Million to $25 million.
- **Application Period**: The application period varies annually, with deadlines typically announced by the U.S. Department of Transportation. Demand for RAISE funding is high, often exceeding available funds.

To learn more, visit transportation.gov/RAISEgrants.

6. 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/.

7. 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.

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 your 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 Annex 4), provided by key partners such as the Washington Emergency Management Division (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.

Referencing examples of letters of support from WGS and WA EMD, included in the annex, can further guide you in crafting a successful request.

Section 6: Tsunami Mitigation Guidance

Mitigation actions represent a proactive and strategic approach aimed at diminishing 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. Examples of such actions include fortifying cleats and moorings, as well as installing sturdier or taller dock piles.

This section begins by examining effective tsunami mitigation actions implemented in other countries and US states and territories, such as Alaska and Hawaii. It then moves to identifying which mitigation actions are most feasible for the Port of Neah Bay, ensuring an effective approach to risk reduction specifically tailored to the unique characteristics of that location. The delineation of responsible parties associated with each mitigation action aims to further enhance clarity regarding the coordination and execution of these crucial measures.

Tsunami Mitigation Actions

We present an array of potential tsunami mitigation actions below, drawing inspiration from successful implementations in other states, territories, and countries. This compilation highlights the practicality, implementation nuances, and overall impact of these mitigation strategies. Covering an expansive range from structural enhancements to community engagement initiatives, 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.

Install Tsunami Signs

Installing tsunami signs is the easiest and most cost-effective mitigation action that a port, harbor, or marina can take to reduce tsunami casualties. Signage can help educate harbor users of the tsunami danger in the area and direct individuals to higher ground during an evacuation. Signs are generally cheap, installation is easy, and upkeep is minimal. Signage posted along roadways and trails alerts people that they are entering or leaving a tsunami inundation zone, so they know of the need to evacuate if a tsunami warning is issued. Signage indicating the location and direction of evacuation routes helps people find and follow established evacuation routes quickly during an evacuation. Each state and territory uses standardized wayfinding signage to designate the extent of inundation areas as well as to designate and define evacuation routes. 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 states, counties, and cities that face tsunami danger have

Figure 40: Tsunami kiosk featuring evacuation route in Oceanside, CA.

built informational kiosks to inform the public of tsunami dangers, such as the evacuation kiosk shown in figure 40.

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

Figure 41: 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 41). 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 free in the dangerous waves. Untethered, freely floating docks pose a danger in a tsunami, essentially becoming massive pieces of debris moved by the waves, possibly with vessels still attached to them.

To help ensure docks remain attached to the sea floor during a tsunami, ports and harbors may choose to increase the size and stability of the pilings. Installing pilings taller than the expected potential inundation levels will help 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.

Reduce Exposure of Petroleum/Chemical Facilities and Storage

Since ports and harbors are where ships go 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, to be 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 onto 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.

Strengthen Cleats and Single Point Moorings

Figure 42: Broken cleat in Neah Bay along Dock A (WA EMD)

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 42). 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.

Improve Movement of Dock Along Dock/Pilings

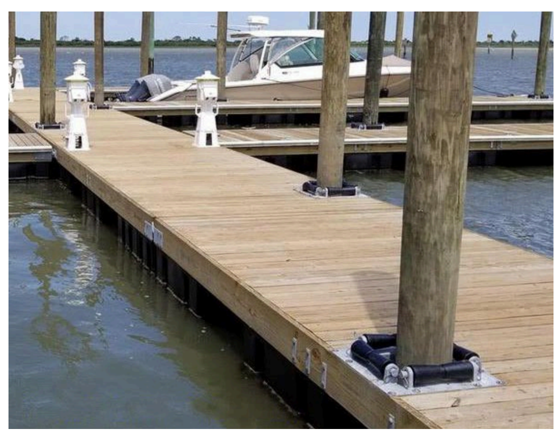

Figure 43: Floating docks with square pile guides for each piling (americanmuscledocks.com).

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 43).

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 on floating debris. Cranes may be needed to hoist and move large debris either in the water or elsewhere on the 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.

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 44). These styles, while common, will not prove as buoyant as docks with a floatation section that spans the entire underside of the dock area.

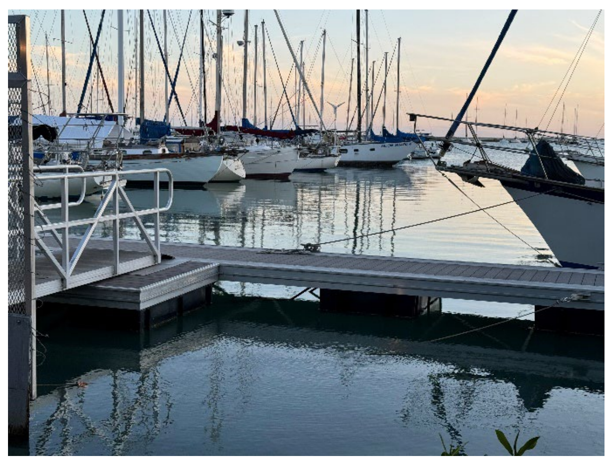

Figure 44: Docks built on floating blocks in Honolulu, Hawaii (WA EMD)

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.

Increase Flexibility of Interconnected Docks and Dock Fingers

Figure 45: 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 45, 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.

Debris Deflection Booms to Protect Docks

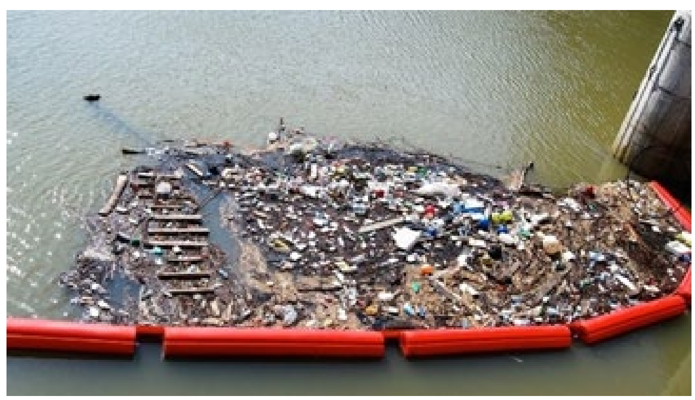

Figure 416: Debris deflection boom (Worthington Waterway Barriers).

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 46. 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. 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 smaller tsunami waves and lighter amounts of debris from 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. 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.

Move Docks and Assets Away from High Hazard Zones

Once a port has been able to identify 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 hazard risk can help save infrastructure and vessels from becoming broken or detached. Moving docks and infrastructure in a port or harbor is a substantial undertaking involving careful planning. New construction may be required 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.

Fortify and Armor Breakwaters

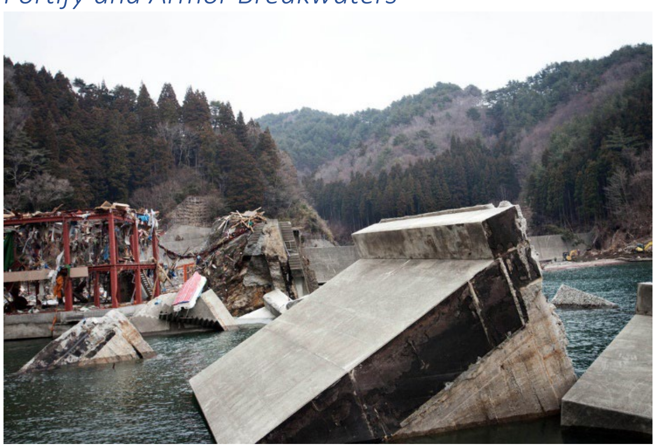

Figure 47: The Kamaishi breakwater, which failed during the 2011 Japanese tsunami (NY Times)

Breakwaters are designed to absorb and deflect strong wave action to protect ships and vessels from rough seas. Unless built to extreme heights, breakwaters are unlikely to block large tsunami waves. The waves would likely overtop the structure, allowing inundation to enter the normally protected area. The strong waves and currents from a tsunami could also cause extreme scouring on infrastructure like breakwaters. The wave action can remove the soil that acts as the foundation of the structure and could even strip away sections of the breakwater itself. Scouring and damage during a tsunami could cause the breakwater to fail, as pictured in Figure 47, allowing even more water to flow into the area. Sudden gaps in the breakwater can also create new, unpredictable, and dangerous currents. Any damage to breakwaters will also need to be repaired post-tsunami, and if damage is severe enough could require full replacement of the structures at considerable time and cost.

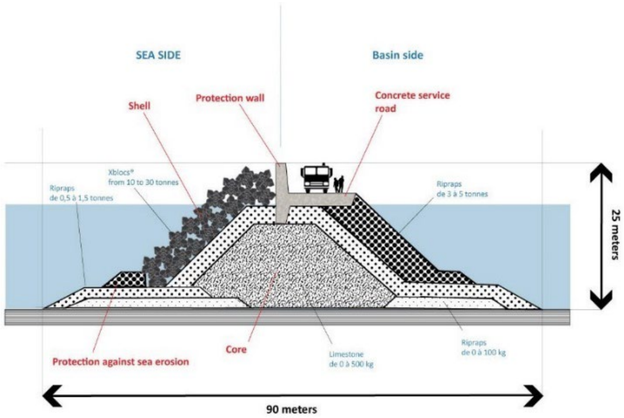

Figure 48: Diagram of fortified breakwater.

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 implies 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 48. Armoring implies covering the seaside of the breakwater with additional materials to help in strengthening the structure. Armoring can be done with actual rock like rubble 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 49.

Figure 49: Photo of fortified breakwater off marina.

Both armoring and fortifying breakwaters are time, resource, and cost intensive efforts which likely requiring 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.

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 are 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 50). 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 50: Breakwater protecting the harbor of Hilo, Hawaii (Big Island Gazette)

Deepen or Dredge Channels Near High Hazard Zones

The effects of a tsunami wave will always be strongest and most pronounced in shallower waters. Just as the wave rises higher as it enters shallower waters, pushing the water further onto dry land, the other effects are similarly more pronounced in locations where the depth is less. 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.

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 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.

Construct Floodgates

Figure 51: 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 51.

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

Feasibility of Tsunami Mitigation Guidance for the Port of Neah Bay

In the comprehensive evaluation of tsunami mitigation actions for the Port of Neah Bay, 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 of the Port of Neah Bay. The applicability of these response actions extends to scenarios involving both a Cascadia Subduction Zone (CSZ) and an Alaskan-Aleutian Subduction Zone (AASZ) 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 of Neah Bay. Conversely, mitigation actions labeled as 'Not Feasible' were deemed as inapplicable, too challenging to execute, or may pose inherent risks that outweigh their potential benefits in the context of life safety and protecting property and were not included or expanded on.

This nuanced assessment provides an understanding of the viability and appropriateness of each mitigation action, facilitating a targeted and customized approach to tsunami preparedness and mitigation for the Port of Neah Bay in the face of potential seismic events from both the Cascadia and Alaskan-Aleutian Subduction Zones.

Mitigation Actions	Feasibility for The Port of Neah Bay
Install Tsunami Signs	Feasible
Increase Size and Stability of Dock Piles/Increase Height of Piles to Prevent Overtopping	Feasible
Increase Flexibility of Interconnected Docks	Feasible
Strengthen Cleats and Single Point Moorings	Feasible
Fortify and Armor Breakwaters	Needs Review
Reduce Exposure of Petroleum/Chemical Facilities and Storage	Needs Review
Acquire Equipment/Assets to Assist in Response Activities	Needs Review
Improve Flotation Portions of Docks	Needs Review
Deepen or Dredge Channels Near High Hazard Zones	Needs Review
Move Docks and Assets Away from High Hazard Zones	Not Feasible
Widen Size of Harbor Entrance to Prevent Jetting	Not Feasible
Construct Floodgates	Not Feasible
Construct Breakwaters Farther Away from the Port	Not Feasible

Movement of Docks Along Pilings	**Not Feasible**
Debris Deflection Booms to Protect Docks	**Not Feasible**

Install Tsunami Signage

Feasibility of Mitigation Action: Feasible

This is a straightforward action for the Port of Neah Bay to implement, and there is a significant need for improved signage in areas with high vessel traffic, such as near the Makah Marina. The Makah Tribe has already emphasized the importance of continuing outreach and education to mariners, as represented with existing signage in Makah Marina (Figure 52), and increasing signage in the Marina area aligns well with these efforts.

Figure 52: Educational signage about boater safety in Makah Marina that could be replaced with signage that includes tsunami protective action measure recommendations. (WA EMD)

Currently, there is limited tsunami-related educational and wayfinding signage in Neah Bay. As part of a broader initiative, the Tribe can work with Washington Emergency Management Division to review their wayfinding study results to inventory existing signage and identify optimal locations for new signage. This initiative could include wayfinding signs (e.g., tsunami evacuation route, tsunami arrows, evacuation route information) and informational signs educating port users about tsunami risks, alerts, and evacuation procedures.

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

Feasibility of Mitigation Action: Feasible

The dock piles at Neah Bay, particularly at Dock A, Dock B, and T-Dock, were originally constructed in 1995 with hollow designs intended for vessels averaging 40 feet in length. However, the marina now accommodates much larger vessels, some exceeding 100 feet, which places significant stress on the existing infrastructure. Over the years, the hollow pilings have shown signs of flexing and bending, especially during winter storms when winds can reach up to 50 mph. This structural stress is a growing concern for the long-term durability and safety of the docks.

The Tribe has recognized the need to increase the size and stability of these dock piles, focusing on replacing the hollow pilings with solid ones that can better withstand the weight and dynamic forces exerted by larger vessels and extreme weather conditions. While increasing the height of the pilings is not a primary focus—given that the current pilings are likely sufficient to prevent overtopping from the more frequent distant tsunamis—there is an awareness that climate change and sea level rise could necessitate future adjustments to piling heights. As sea levels rise, the tribe may need to explore this option further to ensure continued protection against potential overtopping.

In addition to addressing the piling issues, the Tribe has already undertaken significant seismic retrofitting measures. In 2013, Dock A underwent a seismic retrofit designed to withstand a 9.0 magnitude earthquake. This retrofit included the installation of a gangway engineered to collapse in a controlled manner during a seismic event, while the main dock was reinforced to remain intact. Despite these upgrades, the retrofitted pilings are still subject to the same stresses from large vessels and marine life (Figure 53) particularly at T-Dock, which has seen significant wear due to the weight of sea lions and the dynamic forces from the vessels moored there.

Figure 53: Sea lions that sunbathe on the docks have warped the hardware and damaged infrastructure at Makah Marina (WA EMD)

The Tribe is also in ongoing discussions with the U.S. Army Corps of Engineers regarding the interaction between the pilings and the breakwater. The breakwater, which is crucial for protecting the Marina from wave action and storm surges, must be considered in any piling modifications. Ensuring that the reinforced pilings work in tandem with the breakwater is essential for the overall stability and resilience of the marina's infrastructure.

The strategy's emphasis on increasing the size and stability of dock piles is well supported by findings from the Makah Marina Facility Condition Assessment. The report indicates significant wear and deterioration of dock infrastructure, particularly at Docks A, B, and C, where advanced deterioration is affecting the Marina's ability to handle larger vessels. The hollow design of the pilings, originally constructed for smaller vessels, is noted as insufficient for the larger vessels now utilizing the marina. Page 24 of the report emphasizes the need to address urgent repairs and suggests that modifications to the pile structures may be necessary to accommodate future sea-level rise and climate change impacts

The current PIDP grant application includes funding to replace the hollow pilings at Dock A, Dock B, and T-Dock with solid ones. This will enhance the docks' ability to handle larger vessels and resist the forces of extreme weather. While increasing piling height is not an immediate focus, future considerations for climate change and sea level rise could be incorporated into ongoing infrastructure planning.

Increase Flexibility of Interconnected Docks and Dock Fingers and Improve Flotation of Docks

Feasibility of Mitigation Action: Feasible

The dock infrastructure at the Port of Neah Bay presents a complex mix of aging wooden and concrete components that face significant wear and environmental challenges. The wooden docks, originally installed in 1997, are showing considerable signs of rot and deterioration. This aging infrastructure requires ongoing maintenance to address the effects of wear and is anticipated to eventually necessitate complete replacement. In response to these issues, concrete docks have been introduced to replace some of the older wooden sections. However, these concrete docks are not immune to damage and require attention.

A significant challenge affecting the docks is the accumulation of marine life, including barnacles and mussels, which attach themselves to the dock surfaces (Figure 54). This encrustation causes physical damage by scraping and eroding the dock materials, accelerating wear and contributing to structural instability. Additionally, the weight added by these organisms stresses the docks further. Marine life also impacts operational efficiency by obstructing water lines and fueling systems, which can lead to delays and increased maintenance costs. Environmental considerations are also important, as uncontrolled marine growth can disrupt the balance of the local marine ecosystem.

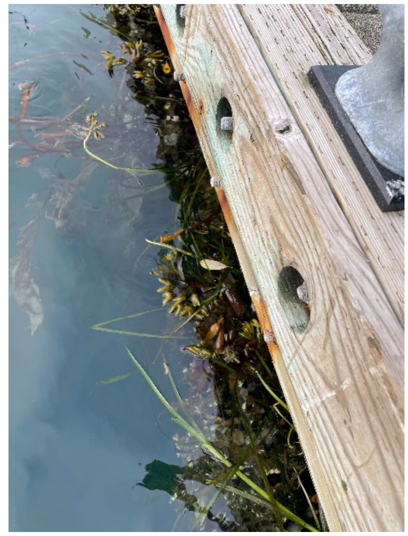

Figure 54: Barnacles and mussels on bottom of docks at Makah Marina (WA EMD)

Sea lions have compounded these issues by sunbathing on the docks and causing physical damage. Their presence not only harms the dock ends but also poses risks due to their aggressive behavior. Efforts are underway to repair and strengthen the dock ends to mitigate this additional damage.

Current projects address several critical aspects of dock infrastructure. The removal of the “old bay fish dock” and “high tide’s pier” is scheduled due to their severe deterioration from storms and king tides. Additionally, submerged vessels and marine debris are being cleared from the bay to improve navigability and environmental quality.

Recent upgrades include the seismic retrofitting of the Makah Fishing Dock, designed to withstand a 9.0 earthquake. This retrofit incorporates a collapsible gangway to ensure the dock remains functional during seismic events. Despite these improvements, concerns about dock height in extreme tsunami scenarios or due to rising sea levels remain. Future enhancements will be considered to further improve resilience against such risks.

The recommendation to increase the flexibility and improve the flotation of docks is directly supported by the Makah Marina Facility Condition Assessment, which highlights structural instability and deterioration of the dock systems. The report specifically notes deterioration in the floating dock systems, with advanced damage to rub boards, timber components, and dock hardware, particularly at the offshore ends of Docks A, B, and C (p. 24). The assessment also identifies that the freeboard of certain sections has dropped below the original design specifications, which aligns with your strategy to enhance the resilience and flotation of the docks. The tribe’s current PIDP grant application includes specific provisions to fund the redesign and reinforcement of the dock piles at Dock A.

Strengthen Cleats and Single Point Moorings

Feasibility of Mitigation Action: Feasible

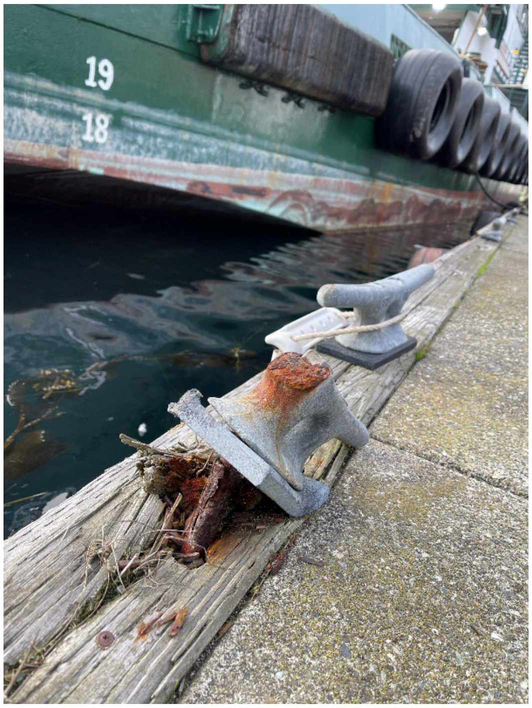

Figure 55: Cleats broken and torn from Dock A next to large vessel (WA EMD)

The cleats and moorings at the Port of Neah Bay, particularly at Dock A, are currently facing critical challenges due to the increased size and weight of vessels now using the Marina. Originally designed for smaller fishing vessels averaging 40 feet, the docks are now accommodating much larger vessels, including a tugboat, which has placed significant stress on the existing infrastructure.

The cleats, made of metal, are showing severe signs of wear and deterioration (Figure 55). Many are rusting, breaking in half, and pulling away from the rotted wood below them. This degradation has compromised the ability of the cleats to securely moor vessels, creating a significant safety hazard. The instability of these mooring fixtures not only endangers the vessels themselves but also the dock infrastructure.

The situation is further exacerbated by the potential impact of a tsunami generated by an Alaska-source earthquake. The increased current speeds and wave action during such an event could easily rip the already compromised cleats from their moorings, potentially dragging the vessels with them. Given that normal tidal conditions and storms have already caused notable damage, the force of a tsunami could be catastrophic. This makes the strengthening of cleats and moorings a top priority for the port.

Addressing this issue involves replacing the existing cleats with more robust, durable alternatives that can better support the current and future vessel sizes. These upgraded mooring fixtures would enhance the security and stability of the dock infrastructure, ensuring that larger vessels, including the tugboat, are safely moored and that the dock remains functional and secure.

The Makah Marina Facility Condition Assessment highlights advanced deterioration in dock infrastructure, particularly in the thru-rods and cleat hardware at Docks A, B, and C. The report notes that the existing cleats are rusting, breaking, and pulling from rotted wood, compromising their ability to secure vessels (p. 24, Makah Marina Facility Condition Assessment). These findings directly support the strategy's emphasis on strengthening the cleats and moorings to handle larger vessels and withstand dynamic forces, such as those posed by tsunamis. The report also emphasizes the need for urgent replacement of structural hardware and cleat bolts to ensure the safety and functionality of the docks. This assessment provides a robust technical basis for upgrading mooring infrastructure, aligning well with the mitigation strategy's goals. The Tribe's current PIDP grant application includes provisions for the replacement and strengthening of cleats and moorings. This funding is critical to upgrading these mooring fixtures to handle the increased demands placed on them by larger vessels and to prevent potential disasters during extreme weather events or tsunamis.

Fortify and Armor Breakwaters

Feasibility of Mitigation Action: Needs Review

The jetty at the Port of Neah Bay, originally constructed to support the Marina and protect the harbor, has faced a series of significant issues over the years. These problems have been exacerbated by environmental factors and changing coastal dynamics, highlighting the need for ongoing attention and maintenance.

The jetty, built as an Army Corps of Engineers project, was designed to stabilize the harbor and control sediment movement. However, its effectiveness has diminished over time due to several factors. Coastal erosion, sea level rise, and storm events have all contributed to the jetty's degradation. The removal of the jetty at Evan’s Mole, intended as a mitigation measure during marina construction, led to unexpected consequences, including increased beach erosion and sediment accumulation in the marina. This has impacted clam beds and navigability, revealing the complex interplay between jetty structures and natural coastal processes.

The Army Corps of Engineers, responsible for the construction and maintenance of the jetty, has been involved in addressing these issues. Their role includes regular inspections and repairs to ensure the jetty remains functional. However, challenges such as sediment accumulation and coastal erosion have outpaced the Corps' maintenance efforts. For instance, the Army Corps has undertaken dredging projects to address sediment buildup but has not conducted significant dredging since 2009. This has left some issues unresolved, including ongoing sediment transport into the Marina.

The relationship between the Port of Neah Bay and the Army Corps of Engineers is crucial in managing the jetty and addressing its issues. While the Army Corps is responsible for the jetty's maintenance and repair, there have been challenges in coordinating efforts and securing timely interventions. The Port has been working to collaborate with the Army Corps to develop strategies for improving the jetty's resilience and effectiveness. This includes exploring options for strengthening the jetty and mitigating further erosion and sediment issues.

The breakwaters at Neah Bay that are also built and maintained by the Army Corps of Engineers play a crucial role in shielding the marina from the powerful forces of the ocean. Positioned farther out in the harbor, these structures are designed to absorb and deflect wave energy, providing calmer waters within the bay. However, there is a significant knowledge gap regarding their current condition and overall effectiveness.

Although the breakwaters appear to be high enough to prevent overtopping from a distant Alaska tsunami, their resilience under such extreme conditions remains uncertain. The capacity of these structures to withstand severe water loads, storm surges, and king tides is not well understood. This uncertainty raises concerns about their ability to manage the forces imposed by such events effectively.

Detailed information about the construction, materials, and maintenance of the breakwaters is limited. Understanding when they were built, what materials were used, and the extent of their ongoing maintenance will be essential in evaluating their current state. This lack of detailed knowledge underscores the need for a comprehensive assessment.

To address these uncertainties, it would be prudent to conduct a thorough study to evaluate the breakwaters' strength and resilience. This study should assess their structural integrity and performance under extreme conditions, including tsunamis, storms, and sea level rise. Collaborating with the U.S. Army Corps of Engineers could provide valuable insights and resources for this evaluation. Their expertise could help determine whether the breakwaters need upgrades and address broader concerns related to storm events, king tides, and rising sea levels.

By undertaking this assessment and exploring potential partnerships, the Makah Tribe can gain a better understanding of the breakwaters' effectiveness and make informed decisions to enhance their ability to protect Neah Bay against future challenges. The current PIDP grant application includes some funding for maintaining and potentially enhancing the breakwater, though additional resources may be needed for a full fortification project.

Reduce Exposure of Petroleum/Chemical Facilities and Storage

Feasibility of Mitigation Action: Needs Review

The Marina at Neah Bay includes several facilities that store hazardous materials, including ammonia stored in a building on Dock A and within the ice plant. This chemical poses a significant risk, particularly in the event of a leak, which could be exacerbated by natural disasters such as tsunamis or earthquakes. The Tribe has recognized the need to reduce the exposure of these facilities by either relocating them to safer areas or enhancing the protective measures around them.

Currently, the Tribe is assessing the risks associated with these storage locations and is in the process of identifying the vendor responsible for the delivery and maintenance of the ammonia. The goal is to ensure that all safety protocols are up to date and that the facilities are either moved out of high-risk zones or adequately reinforced to withstand potential hazards. This might include upgrading containment systems, installing leak detection technologies, or building barriers to protect the facilities from external impacts.

Acquire Equipment/Assets to Assist in Response Activities

Feasibility of Mitigation Action: Feasible

Currently, the Makah Tribe owns one police response vessel that can be used in emergencies. With this said, there are other emergencies where acquiring additional response assets could be beneficial to the Makah Tribe. Neah Bay is a critical hub for maritime traffic, including oil tankers and large container ships, which increases the likelihood of maritime incidents, such as oil spills. The Tribe has a long history of oil spill response, with trained members ready to deploy in the event of an emergency. Federal funding through the OSLTF may be available to support the acquisition of oil spill response equipment which could be beneficial for general response as well as post tsunami clean up. The Tribe recognizes the need for additional equipment and assets to enhance their overall response capabilities, particularly in light of increasing maritime traffic and the potential for more frequent and severe storms.

Current response assets include basic tools and equipment, but there is a need for specialized response vessels, booms, and spill containment equipment that can be rapidly deployed. The tribe is also considering the acquisition of drones and other technology that could improve their ability to monitor and respond to incidents in real-time. This equipment is essential not only for oil spill response but also for dealing with potential chemical spills or other maritime emergencies like tsunamis that could impact the port and surrounding areas. Considering the overlapping hazards additional response assets could be beneficial in opening up a strong case for mitigation funding or other funding opportunities.

Move Docks and Assets Away from High Hazard Areas

Feasibility of Mitigation Action: Needs Review

The Tribe has taken steps to move critical infrastructure away from high hazard zones, particularly with the ongoing project to relocate the Tribal Clinic above the tsunami inundation zone. This $15 million project includes expanded provider sleeping quarters and a larger pharmacy, ensuring that essential services remain operational even in the event of a tsunami. While specific plans to move docks or other maritime assets have not been outlined, this project reflects the tribe's broader commitment to reducing vulnerability to natural disasters.

The Tribe may consider relocating other critical assets, such as fuel storage facilities away from areas most at risk from tsunamis or severe storms. This would involve a comprehensive assessment of the risks associated with current dock locations and the development of a strategic plan to either protect or relocate these assets. With this said, moving the maritime assets such as docks would not be as feasible a measure as others since they already are protected by the breakwaters and jetty in Makah Marina. While efforts to consider relocation of other assets should be prioritized, docks should not be.

The Makah Marina Facility Condition Assessment provides insight into infrastructure vulnerability but does not directly recommend relocating docks or assets. However, the report notes that sections of the marina, particularly Dock A, are more exposed to weather and vessel damage than others, which could justify the strategy's call for reducing asset exposure in high-hazard zones (p. 24, Makah Marina Facility Condition Assessment). The ongoing wear on the offshore ends of Dock A supports the idea that relocation or reinforcement of exposed sections may be necessary to protect infrastructure against future hazards.

Deepen or Dredge Channels Near High Hazard Zones

Feasibility of Mitigation Action: Needs Review

The Marina at Neah Bay is experiencing ongoing sedimentation issues, particularly near Dock E and the fish gap, which is an area initially designed by the Army Corps of Engineers. The sediment buildup threatens to block access to dock slips and reduce revenue by making parts of the Marina impassable. Despite a dredging project conducted by the Army Corps in 2023, which aimed to remove between 24,000 to 36,000 cubic yards of material, only 9,000 cubic yards were actually removed.

The Tribe continues to advocate for further dredging and sediment management to maintain clear navigation channels, especially near Dock E where normal tides, storms, and tsunamis can exasperate sedimentation and create unnecessary flow of water into the Marina. This includes ongoing discussions with the Army Corps to ensure that future dredging efforts are more effective and address the sedimentation problems comprehensively. The Tribe is particularly concerned about the long-term impact of these sedimentation issues on Marina operations and the potential for them to exacerbate during extreme weather events.

The facility assessment does not specifically address sedimentation issues or dredging needs, though it does emphasize ongoing deterioration of Marina infrastructure, which could exacerbate sedimentation problems. While the report does not discuss sediment buildup, future studies should consider incorporating dredging activities to maintain navigability and reduce risks associated with storm surges and tsunamis. The current PIDP grant includes provisions for sediment management, although additional resources may be needed to achieve the desired depth and channel maintenance.

Section 7: Conclusion and Next Steps

The threat of tsunamis to the maritime community of the Makah Tribe and the Port of Neah Bay is significant, with potential damage to infrastructure, vessels, and hazardous conditions for those on the water, shoreline, and within the inundation zone. This could render the Port inoperable for an extended period, disrupting vital fishing and maritime tourism activities, causing substantial revenue loss, and deeply affecting the cultural and environmental significance of the Port. For the Makah people, the Port is not just an economic hub, but a critical link to their cultural heritage and deep-rooted connection to the sea.

The Makah Tribe's relationship with the ocean, passed down through generations, is integral to their identity and is reflected in cultural practices such as fishing, whaling, and canoe racing. These traditions, celebrated during events like Makah Days, connect the community to their ancestral lands and waters. A tsunami that devastates the Port would disrupt not only infrastructure but also these traditions, threatening the cultural continuity of the Makah people and leaving a lasting impact on future generations.

As the Port faces increasing risks from natural disasters—including tsunamis, sea-level rise, storm surges, and king tides—a multi-hazard approach to mitigation is essential. While these hazards may not directly result from tsunamis, addressing them through creative use of funding can also support tsunami mitigation efforts, enhancing the overall resilience of the community. Holistic mitigation strategies will help preserve both the economic vitality and the cultural significance of the Port for future generations.

The restoration of the Port after a tsunami will require significant resources, time, and effort, but the cultural impact may be even greater. Losing access to the sea, which is central to the Makah people's identity, would be felt across generations. Mitigation efforts must therefore prioritize the protection of cultural heritage alongside infrastructure, ensuring the Makah Tribe's maritime traditions endure through future challenges.

Both the Alaskan Aleutian Subduction Zone (AASZ) and Cascadia Subduction Zone (CSZ) scenarios emphasize the critical need to bolster response strategies and invest in infrastructure that can withstand the significant forces of a tsunami. Moving forward, the Port can adopt measures and engage in both mitigation and response actions to enhance its resilience and ensure the safety of its customers, tenants, and the public in the event of a tsunami. While some of these actions are relatively straightforward and manageable, others may necessitate more time, planning, and external assistance.

Cascadia Subduction Zone Tsunami Impacts

A tsunami generated by a Cascadia Subduction Zone (CSZ) earthquake would have devastating consequences for the Makah Tribe and the Port of Neah Bay. The CSZ scenario projects significant offshore wave heights, with up to 45 feet on the Makah Bay side and 30 feet on the Neah Bay side. These waves would overtop jetties, overwhelm pilings, and inundate vast areas, including the Wa'atch River valley, Neah Bay, and Makah Bay. Maritime infrastructure, including docks, piers, and vessels, would face severe damage, with vessels likely to be washed ashore, grounded, or capsized due to the violent forces of the waves and significant debris carried by the water. Current speeds in excess of 9 knots would further exacerbate the danger, creating hazardous whirlpools, eddies, and potential collisions with debris. The risk to life and safety is immense, with only 15 to 20 minutes of evacuation time available before the first wave hits after the earthquake. Additionally, coseismic subsidence, or land sinking, is expected to lower the elevation by as much as 11-13 feet, leading to long-term flooding risks and potentially rendering key infrastructure, like the Makah Tribal Marina, permanently submerged or damaged. The magnitude of this event underscores the critical need for robust response planning, community awareness, and infrastructure improvements to mitigate future risks.

Alaska-Aleutian Subduction Zone Tsunami Impacts

A tsunami triggered by the Alaska-Aleutian Subduction Zone (AASZ) would be less catastrophic compared to a CSZ event, but it still poses significant risks to the maritime infrastructure and safety of the Makah Tribe. In this scenario, offshore wave heights are lower, reaching up to 16 feet in Makah Bay and 10 feet near Neah Bay, with less extensive inundation than a CSZ tsunami. While there would be more time for response—approximately 3 hours and 40 minutes before the first wave reaches Neah Bay—the danger remains for vessels, piers, and docks, particularly in areas where current speeds reach 6-9 knots. Although the Waadah Island Jetty may not be overtopped, high-speed currents could breach weak points, putting nearby infrastructure at risk. Areas near the mouth of the Wa'atch River and Hobuck Beach would still experience flooding, with water traveling several miles up the river. Mariners would face dangers from potential vessel grounding during drawdown and unpredictable currents that could cause collisions or capsize boats. This scenario highlights the importance of timely decision-making, as well as enhancing mitigation efforts through strategic infrastructure improvements like reinforcing jetties and dredging shallow areas to reduce drawdown impacts.

Recommended Response Actions

Some of the listed response actions require minimal planning, time, or resources to accomplish, while others may already be in the planning stages or partially implemented. Enhancing and refining these actions is crucial to bolstering the Port's tsunami response capabilities. However, some response actions warrant further review to assess their suitability for the Port, particularly in the context of local or distant source tsunamis. Achieving effectiveness in these response actions will necessitate additional time, research, and planning. Although certain actions may be deemed unfeasible by the Port, prioritizing the development of robust and adaptable response plans remains essential in mitigating risk, preserving lives, and enhancing overall resilience.

Here's a summary of the response activities recommended for the Port of Neah Bay and Makah Emergency Management, categorized by feasibility and the need for review:

Feasible Response Measures

- **Identify Boat Owners/Individuals Who Live Aboard Vessels and Establish Notification Processes:** Makah Emergency Management should work with the Port of Neah Bay to enhance communication with boat owners, especially liveaboards. Updated moorage agreements and communication channels such as SMS, email, apps, and NOAA radios will help ensure timely notifications. A comprehensive tracking system for managing and updating alert lists is also needed to improve preparedness.
- **Shut Down Port Infrastructure Before Tsunami Arrives:** While there are no current SOPs for shutting down port infrastructure, it is feasible for the Port to turn off power, water, and fuel lines once a tsunami alert is received. Clear communication channels and established procedures should be developed to guide actions during an emergency, with the Tribal General Manager overseeing these efforts.
- **Evacuate Public/Vehicles from Waterfront Areas:** Evacuating waterfront areas is achievable, especially for distant tsunamis like the AASZ scenario. Public safety personnel will coordinate

evacuations, including road blockades and siren alerts. Further refinement of the Regroup alert system is required to ensure that specific messages are directed to the appropriate groups, and comprehensive emergency plans should be digitized for easy access.

- **Personal Floatation Devices/Vests for Port Staff:** The Port plans to procure additional life rings and flotation jackets to enhance water safety for staff, crew, and beach users. Staging life rings in easily accessible areas is a feasible and proactive measure.
- **Informing and Coordinating with Key First Responders During a Tsunami:** Strengthening communication protocols with EMS, fire, and police departments is feasible and essential. Currently, responders use police scanner radios, but the alert system could be streamlined. Reviewing and updating Regroup lists, along with exploring enhanced communication technologies, will improve coordination.
- **Activate Incident Command at Evacuation Sites:** Moving the Emergency Operations Center (EOC) to the new Emergency Management Office (EMO) outside the inundation zone is feasible. The new EOC should be fully equipped and regularly inventoried to ensure operational readiness. Additionally, FEMA's ICS training for key personnel will further enhance incident command capabilities.

Response Actions Needing Review

- **Remove or Secure Hazardous Materials Used or Owned by Port:** The unstable fuel dock at the Port poses a significant risk during a tsunami. SOPs for securing hazardous materials and shutting off fuel lines are needed to prevent environmental contamination. Automatic shutoff systems should also be explored.
- **Move Vessels Out of the Port:** Moving vessels out of the port during a tsunami poses challenges due to high current speeds and the lack of authority over vessel owners. Coordination with local, state, and federal agencies is needed to determine feasibility and to establish safe staging areas for vessels.
- **Restrict Traffic Entering the Port by Land and Aid in Traffic Evacuation:** Traffic evacuation is not feasible for a local CSZ tsunami due to the short wave arrival time, but it could be possible for a distant AASZ scenario. Coordination with the Makah Tribal Police is needed to develop a comprehensive evacuation strategy, including pedestrian and vehicular traffic control.
- **Activate Mutual Aid System as Necessary:** The Tribe has an established mutual aid agreement with the Clallam County PUD, but further documentation and review of all mutual aid agreements are needed. Training staff on how to activate mutual aid systems during a tsunami is critical for ensuring a coordinated response.
- **Pre-Stage Emergency Equipment Outside Affected Area:** Relocating the EOC to a safer location is recommended, but more equipment and resources need to be staged outside the inundation zone. A mobile EOC, Starlink systems, and reliable communication devices should be inventoried and tested regularly to ensure readiness.
- **Pre-Identify Personnel to Assist in Rescue, Survey, and Salvage Efforts:** Port staff lack the expertise to conduct post-tsunami assessments, so engaging maritime construction companies and engineering firms for facility evaluations is necessary. The Community Emergency Response Team (CERT) program could be expanded to support first responders during rescue and salvage operations.
- **Secure Moorings of Tribal-Owned Vessels:** While it is not feasible for the Port to secure all moorings, they can provide recommendations to private vessel owners about proper mooring during a tsunami. Scenario-specific alert messaging and guidance from WA EMD will help boaters prepare.

Further, the Port should continue to expand its planning for a tsunami over time as much as possible. Conducting regular exercises and training, with local emergency management, will help ensure that response procedures are followed in an effective manner during a tsunami and can help identify areas for improvement prior to an actual incident. Education and outreach to Port tenants and other users of the Port's facilities will help them understand the tsunami hazards and risks, how to get tsunami alerts, and what to do to protect themselves and their property. The Port may even determine some response actions are the responsibility of tenants, in which case, education and outreach to those individuals can help them better understand their risks and what actions they should take to reduce those risks. Much like mitigation efforts, every additional step taken to improve response capability for a tsunami will help the Port save lives, protect property, and shorten recovery times.

Recommended Mitigation Actions

To help mitigate the potential damage to Port infrastructure and tenant property and reduce potential casualties, it is recommended that the Port consider taking or augmenting these mitigation actions. Some mitigation actions offer straightforward solutions that can significantly decrease potential damage and enhance safety for individuals at the Port's facilities. However, securing funding for these actions may require careful review, advocacy, and coordination to identify existing or alternative sources of financial support. Conversely, certain mitigation measures may demand substantial resources and expert consultation for full implementation. Despite the resource-intensive nature of these measures, their potential to minimize facility damage and reduce casualties underscores the importance of considering and implementing them whenever feasible. It is advisable for the Port to assess these options and, when appropriate, incorporate them into its long-term planning for infrastructure maintenance, rehabilitation, and future upgrades.

- **Install tsunami signage at high-traffic areas in Makah Marina:** Work with Washington Emergency Management Division to review existing tsunami-related signage and install new wayfinding and informational signs in critical areas such as Dock A, Dock B, and T-Dock. This will increase mariner and visitor awareness of tsunami risks and evacuation routes.
- **Replace hollow dock pilings at Dock A, Dock B, and T-Dock with solid pilings:** Upgrade the hollow pilings originally built for smaller vessels with solid ones to better handle the weight and size of larger vessels currently using the marina. Ensure these new pilings are durable enough to withstand extreme weather and possible future sea-level rise.
- **Strengthen cleats and single-point moorings at Dock A and T-Dock:** Replace deteriorating cleats and moorings that are compromised by rust and damage. Upgrade them to more robust alternatives to securely moor larger vessels, including a tugboat, and ensure they can withstand increased forces from tsunamis and normal weather conditions.
- **Increase flexibility and improve flotation of interconnected docks at Dock A and Dock B:** Conduct maintenance and upgrades to improve the structural resilience of wooden and concrete docks. Address the impact of marine life, such as barnacles and sea lions, on dock stability and increase the flotation of dock systems to withstand both daily wear and extreme events.
- **Fortify breakwaters and jetty at Neah Bay to protect against wave action and erosion:** Collaborate with the U.S. Army Corps of Engineers to conduct an in-depth assessment of the breakwater and jetty systems. Explore options to fortify these structures to mitigate coastal erosion, sea-level rise, and damage from future tsunamis.

- **Conduct Assessment of Hazardous Material Containment and Storage Facilities:** An assessment should be conducted to evaluate the ammonia storage at the ice plant on Dock A, along with other potential hazardous material containment areas. This assessment would help determine whether relocating these facilities or enhancing their protective measures to withstand earthquake and tsunami risks is necessary.
- **Acquire additional emergency response assets, including oil spill response equipment:** Invest in new equipment such as response vessels, drones, and oil spill containment booms to enhance the tribe's ability to respond to maritime emergencies and post-tsunami recovery efforts. These assets will support both general and tsunami-specific response needs.
- **Assess the potential to move vulnerable docks and assets away from high-hazard areas:** While the breakwaters and jetty offer some protection, explore the feasibility of relocating high-risk assets, such as fuel storage, out of tsunami-prone zones. Consider moving other critical assets to reduce vulnerability to severe weather and tsunamis.
- **Deepen and dredge channels near Dock E and the fish gap to maintain navigability:** Address ongoing sedimentation issues that are blocking access to dock slips by coordinating with the Army Corps of Engineers for more effective dredging efforts. This will reduce sediment buildup that exacerbates risks during tsunamis and ensures clear navigation channels.

Additionally, the Port can enhance its mitigation efforts through planning, and education of and outreach to its tenants and those using its facilities. By integrating mitigation methods into the Port's long-term planning, the Port can ensure that the more complicated mitigation actions stay on track to be completed in a reasonable time frame. This can also help with budgeting allocation, which will allow the Port to ensure there will be funds to cover the costs for more expensive actions. Engaging in outreach and education with tenants and other users of the Port's facilities will help ensure that tsunami hazards and risks are widely understood by those who occupy and or utilize the Port's property. Helping tenants understand the dangers posed by tsunami waves and encouraging them to take steps to mitigate that risk will help the Port become more resilient overall and assist in recovery efforts.