Tsunami Maritime Response and Mitigation Strategy: City of Bainbridge Island's Eagle Harbor

Bainbridge Island, Washington

2024

EMERGENCY MANAGEMENT DIVISION WASHINGTON

CITY OF BAINBRIDGE ISLAND

WASHINGTON DEPARTMENT OF NATURAL RESOURCES

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Table of Contents

Section 1: An Introduction to Tsunamis

Tsunamis, formidable waves triggered by the sudden displacement of water, pose a significant threat to coastlines across the United States, with Washington State being particularly vulnerable. Local tsunamis generated by nearby seismic 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 additional response time but still carry substantial risks for Washington.

In Section 1, we provide a comprehensive overview of the key mechanisms and risks associated with tsunamis in the region, shedding light on the potential impacts on coastal areas. This section delves into the natural 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.

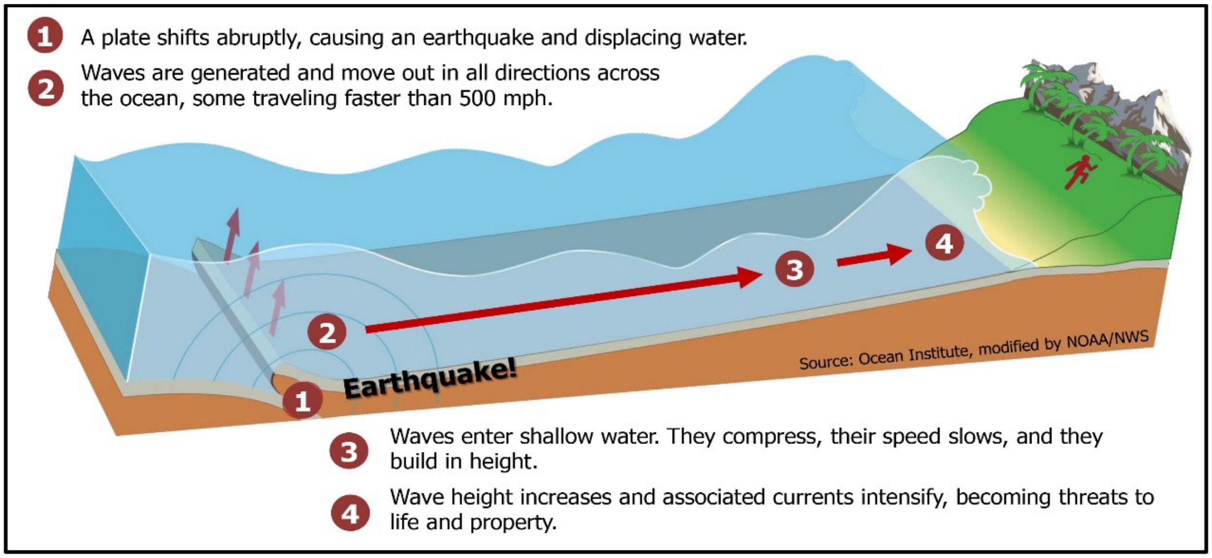


Figure 1: Earthquake generated tsunami diagram (Ocean Institute and NOAA/NWS).

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 CSZ tsunami off the coast of Washington State (WA Geological Survey 2021).

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

An earthquake along the CSZ could produce catastrophic tsunami waves that hit Washington's outer coast within 10-20 minutes in some locations. The last major earthquake along the CSZ occurred in 1700 and produced large tsunami waves and subsidence along the coast. These waves would then hit low-lying parts of the northern inland waters and Puget Sound within two hours or more. Similarly, a large earthquake along the SFZ, such as the estimated magnitude 7.5 event that occurred in 923 C.E., could generate destructive tsunami waves within Puget Sound. Strong currents and water level changes would continue for 12-24 hours or longer. These waves would inundate coastal areas within minutes, with strong currents and significant water level changes persisting for hours. The SFZ scenario also poses unique risks to the densely populated and industrialized areas around central Puget Sound, where the proximity to the fault could exacerbate both shaking impacts and tsunami hazards. As with the CSZ, earthquake shaking along the SFZ could trigger landslides that generate additional localized tsunamis, compounding the immediate impacts. Aftershocks of sufficient size may also produce secondary tsunamis in the days, weeks, and months following major CSZ earthquakes.

Distant Source Tsunamis

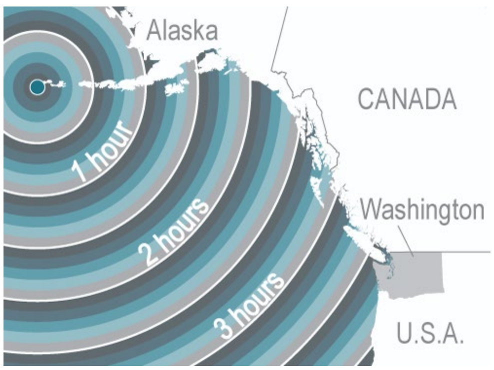


Figure 3: The wave arrival times of a distant tsunami originating off the coast of Alaska (WA Geological Survey 2021)

Distant source tsunamis are tsunamis for which the first waves arrive at a location in over 3 hours; if caused by an earthquake, you will not feel the ground shaking. These tsunamis are most frequently caused by large underwater earthquakes in other parts of the Pacific Ocean basin. The 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 for responsive actions than a tsunami originating off the coast of Alaska where waves would arrive in Washington within 3.5-4 hours.

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

Natural Tsunami Warning Signs

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 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.

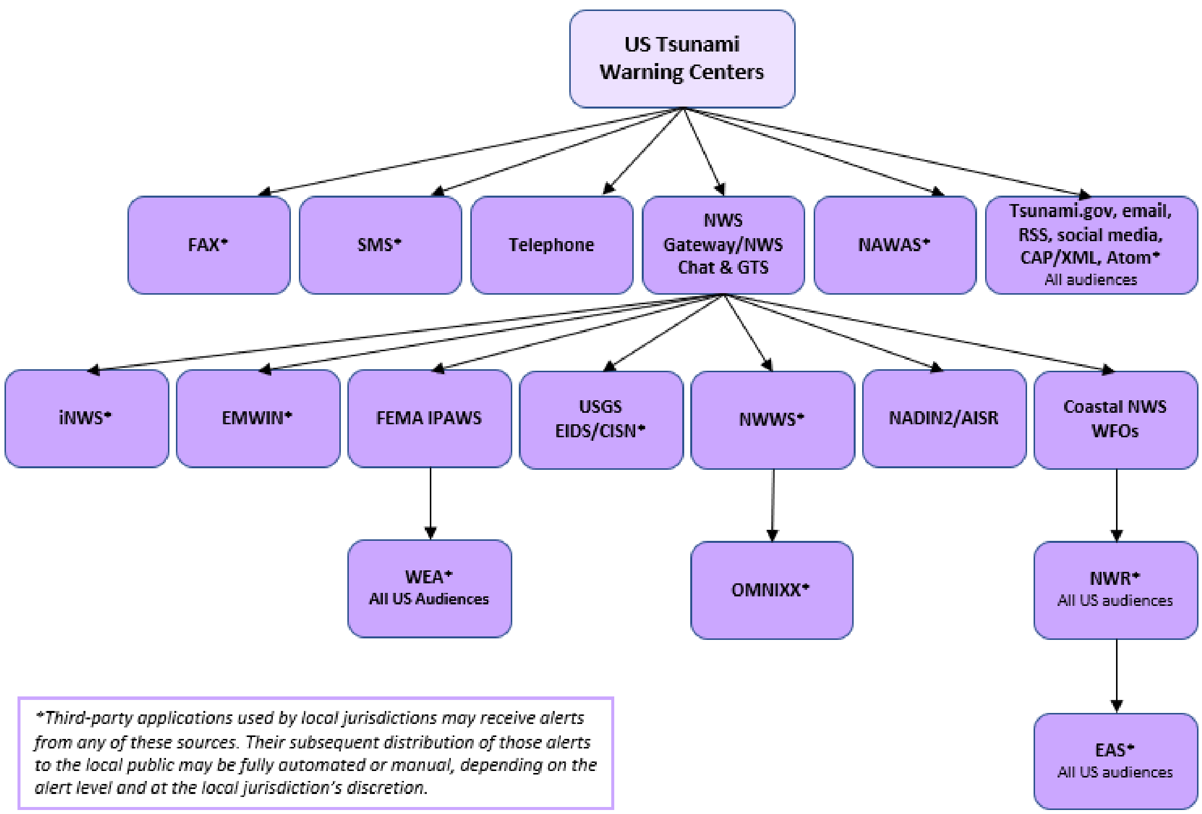


Figure 4: Diagram of tsunami alert dissemination (WA EMD 2024).

Official tsunami alerts are most important for distant tsunamis and can also be useful for people farther from the source of a local source tsunami. For those individuals near the source, such as people on the outer coast for a CSZ tsunami, the impacts could occur too quickly to receive official alerts. 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.

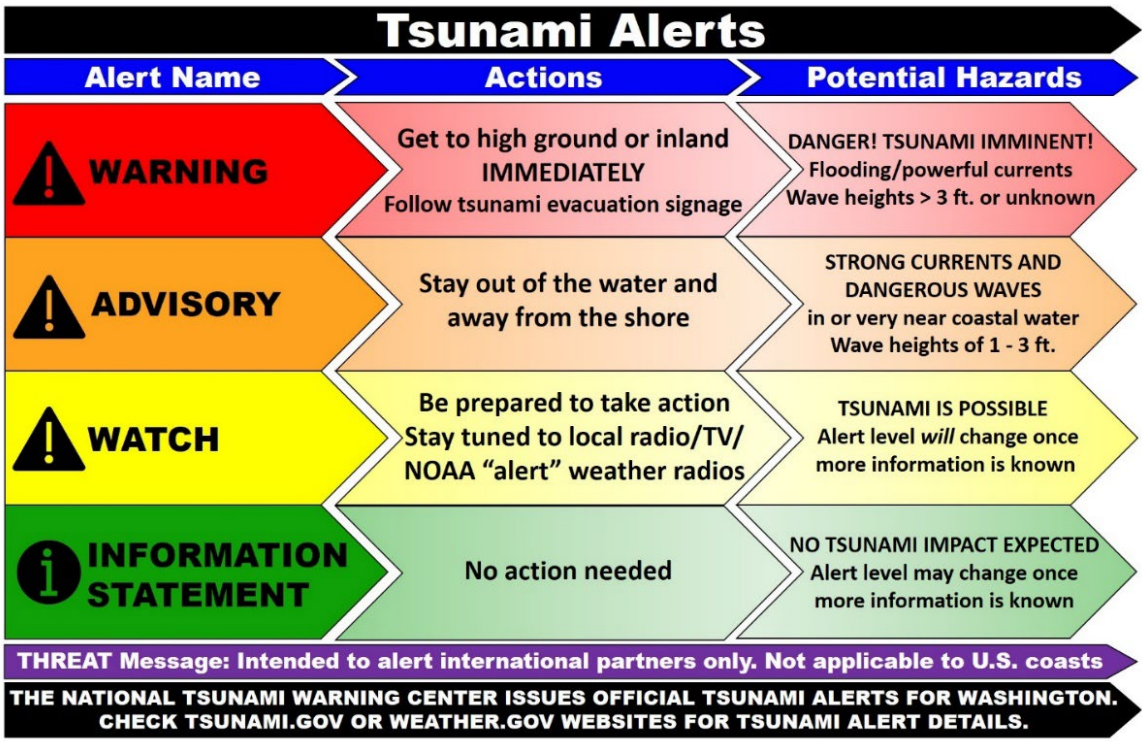


Figure 5: Official tsunami alert levels, associated effects, and protective actions to be taken (WA EMD).

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 tsunami warning centers issue a tsunami warning if the forecast or observed tsunami height exceeds 3.3 feet (1.0 meter) or the impact is unknown.

Tsunami Advisory

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

Tsunami Watch

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

Tsunami Information Statement

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

Receiving Tsunami Alerts

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

- NOAA Weather 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).

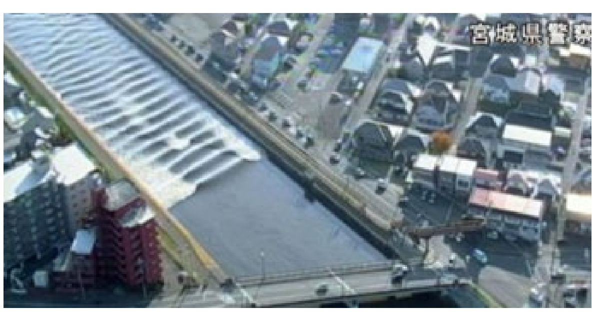


Figure 7: Standing tsunami bore wave in Sunaoshi River, Miyagi Prefecture, Japan 2016. (Miyagi Prefectural Police / Kyodo / Reuters, 2016).

Tsunamis pose many significant hazards for boaters and their vessels. Sudden large fluctuations in water level can 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 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).

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. Tsunamis create and scatter dangerous amounts of debris and hazardous materials that create additional risk of collisions and other secondary hazards such as fires or chemical exposure (Figure 9).

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

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 may persist for 12-24 hours or more.

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

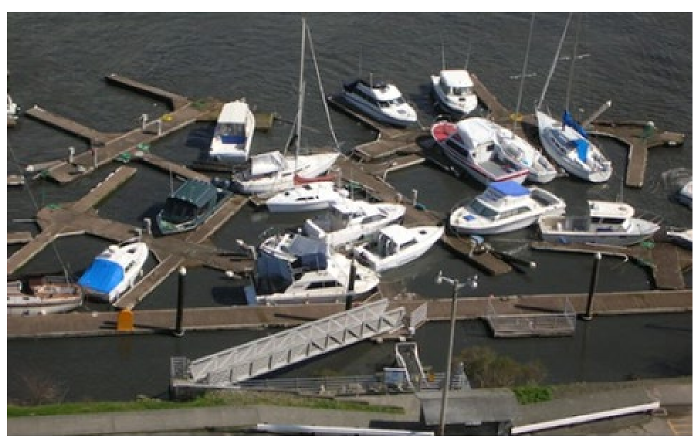


Figure 10: Docks broken from Japan 2011 distant tsunami in Brookings, OR (USCG / Group Air Station North Bend).

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

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 (1 meter) 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 (0.3 to 1 meter) 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). Keep in mind the following:
    - Proceed as perpendicular to the shore as possible
    - Sail directly into wind waves, keeping in mind that wind waves opposed by tsunami currents will be greatly amplified
    - Maintain as much separation as possible from other vessels
    - Synchronize movements with any other vessels to avoid collisions
- At 100 fathoms (600ft) or deeper: If you are already at a location where the water depth is 100 fathoms or deeper, you are relatively safe from the impacts of a tsunami.

After the tsunami

- If you are at an onshore assembly area, check with local authorities for guidance before returning to the inundation zone.
- Do not return to local ports until you have firm guidance from the USCG and local authorities. Local ports could sustain heavy damage from a local tsunami and may not be safe for days, weeks or months.
- 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 the 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 number of provisions, fuel, and equipment on board

- tide stage and conditions on the sea
- whether the vessel has adequate communication with other nearby vessels and authorities on shore (Figure 13)

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.

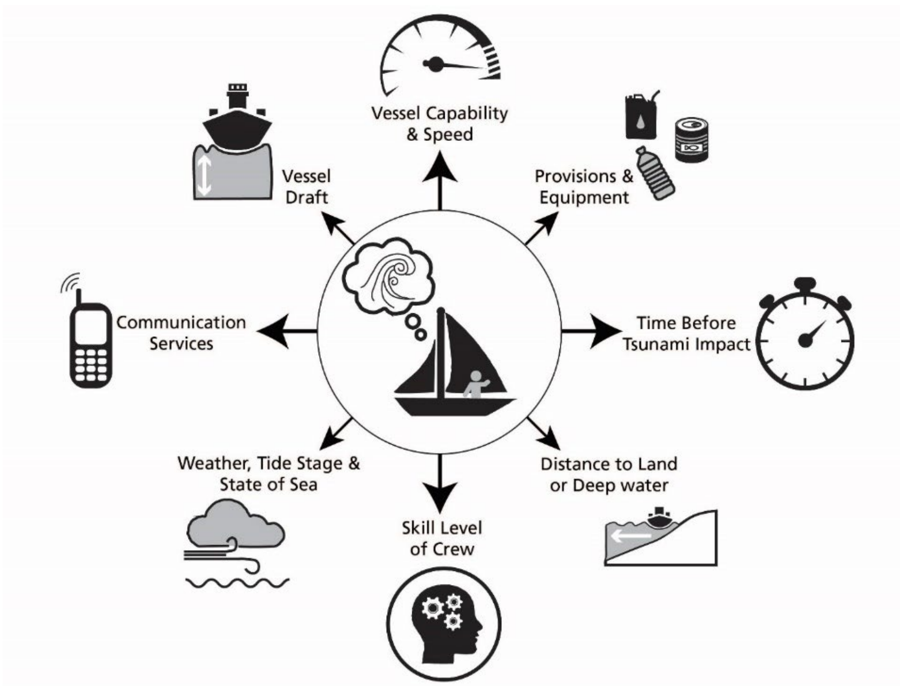


Figure 13: Considerations for boaters who are already offshore during a tsunami (WA Geological Survey).

Section 3: Tsunami Maritime Hazard and Risk Assessment for Bainbridge Island's Eagle Harbor

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

Figure 14: Eagle Harbor head of the bay photographed at dusk, a highly residential community with waterfront property and numerous private marinas (City of Bainbridge Island, 2024)

Introduction to Eagle Harbor and the City of Bainbridge Island Community

Nestled in the heart of Puget Sound, Eagle Harbor is a vital maritime and community hub for Bainbridge Island, serving the island's main town, Winslow. This picturesque harbor exemplifies the island's balance between rich maritime traditions, modern infrastructure, and a strong, interconnected community spirit.

At its eastern end, the Seattle-Bainbridge Island Ferry Terminal stands as one of the busiest in the United States, transporting over 6 million passengers annually across Puget Sound. This critical connection, maintained by two Jumbo Mark-II-Class ferries, links Bainbridge Island to downtown Seattle, facilitating daily commutes, tourism, and regional commerce. Adjacent to the terminal, Washington State Ferries (WSF) operates a shipbuilding and maintenance facility that employs numerous workers. This facility not only sustains the state's ferry fleet but also reinforces Bainbridge Island's role as a cornerstone of maritime operations in the region.

Eagle Harbor is home to a vibrant network of private marinas and the City Dock, which together offer approximately 900 linear feet of moorage, with an additional 80 feet allocated for loading and unloading. These facilities cater to a wide variety of vessels, from recreational boats and fishing crafts to liveaboard yachts, illustrating the harbor's versatility and community-driven focus. The liveaboard community, in particular, adds to Eagle Harbor's dynamic character, fostering a close-knit and collaborative waterfront culture that enriches Bainbridge Island's identity.

Tourism is a cornerstone of Eagle Harbor's vitality, with visitors flocking to Bainbridge Island to experience its natural beauty, vibrant downtown shops, acclaimed restaurants, and cultural landmarks. The City Dock serves as a welcoming gateway for transient boaters, making it easy for visitors to access local attractions and participate in the island's many festivals and events. The downtown area of Winslow, within walking distance of the harbor, thrives as a center for community engagement and local business, ensuring that both residents and visitors feel a deep sense of connection to the island.

Preparedness and community resilience are hallmarks of Eagle Harbor, embodied by initiatives such as the Bainbridge Prepares partnership (between the City of Bainbridge Island, Fire Department, and community non-profit Bainbridge Prepares). Among its key efforts, the Bainbridge Prepares Flotilla group mobilizes private vessels to support the community during emergencies, particularly when conventional transportation routes are disrupted. This dedicated volunteer corps plays a pivotal role in disaster response, aiding in the transportation of staff and supplies, conducting coastal surveys, and ensuring the safety and well-being of residents. This initiative underscores Bainbridge Island's commitment to fostering a resilient and resourceful community that can rise to challenges together.

Eagle Harbor is much more than a maritime hub; it is the lifeblood of a vibrant, engaged community. From the workers at the ferry maintenance facility to the liveaboard residents, from the bustling marinas to the welcoming City Dock, Eagle Harbor represents the spirit of Bainbridge Island—a place where commerce, recreation, and community thrive together. This harmonious blend of maritime tradition, natural beauty, and civic pride ensures Eagle Harbor remains a beacon for both locals and visitors alike.

Background of Earthquake and Tsunami Risk to Eagle Harbor

The location of Eagle Harbor leaves its residents, visitors, and maritime community vulnerable to infrequent but potentially catastrophic geological threats, such as major tsunamigenic earthquakes in Puget Sound and the Pacific Ocean. Of particular concern is the Seattle Fault Zone, which lies directly beneath the Eagle Harbor community. A large earthquake (magnitude 7.2–7.5) on the Seattle Fault could cause severe to violent shaking in Eagle Harbor (MMI 8–9; Figure 15) due to its proximity. Shaking of this intensity could cause slight to significant damage to even specially designed structures. Well-constructed framed buildings might be thrown out of alignment or shifted off their foundations. Poorly built structures could experience severe damage or partial collapse, including the fall of chimneys, factory stacks, columns, walls, and other heavy structures.

Although rare—only one such event has been recorded in the geologic record over the past 16,000 years—a large enough earthquake on the Seattle Fault has the potential to generate a tsunami. That tsunami could reach Eagle Harbor in less than 10 minutes, bringing strong currents and large-scale inundation along the shoreline and low-lying areas. The earthquake could also result in significant coseismic land level changes, with the shoreline shifting by as much as 5.5 feet.

Another significant earthquake hazard for the region is the Cascadia Subduction Zone (CSZ), located approximately 70 miles offshore from Washington's outer coast. The CSZ is capable of producing massive earthquakes, up to or exceeding magnitude 9.0. Such an event could cause very strong to severe shaking (MMI 7–8; Figure 15) in Eagle Harbor, influenced by the local geology. A magnitude 9 earthquake would also generate a tsunami that could impact the entire U.S. West Coast. In Washington's inner waterways, tsunami waves would enter the Strait of Juan de Fuca within 20 minutes of the earthquake, travel through Puget Sound, and reach Eagle Harbor approximately 2 hours and 20 minutes later. Detailed tsunami wave arrival timings are discussed later in this section.

Of note in Eagle Harbor is the Eagle Harbor/Wyckoff Superfund Site, on the southern tip of the harbor entrance. The site was home to a creosote wood-treating facility that was in operation from 1903-1988 and leaked contaminants into the surrounding soils and groundwater (Environmental Protection Agency [EPA], 2023). The EPA identified the facility as a superfund site in 1987 and began cleanup operations. Although the risk at the site itself has been controlled or eliminated, there continues to be creosote contamination in East Beach and North Shoal. Cleanup efforts are still ongoing, and restrictions have been put in place to ensure that the areas remain largely undisturbed. This site has significant implications for future mitigation efforts that will be discussed later in this document.

Eagle Harbor has experienced tsunamis in the past and, despite its resilience, will inevitably face such events again. It is not a question of if, but when, the next tsunami will occur.

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

Figure 15: Abbreviated descriptions of the levels of shaking in the Modified Mercalli Intensity (MMI) scale from an earthquake. USGS ShakeMaps suggests Bainbridge Island's Eagle Harbor could experience VIII-IX (severe to violent) shaking intensities in a Mw 7.2-7.5 Seattle faut earthquake scenario, and VII-VIII (very strong to severe) shaking intensities in a Mw 9.0-9.3 Cascadia Subduction Zone scenario.

This maritime-focused study presents tsunami modeling results from two possible local tsunamigenic sources for this region. Scenario one represents a tsunami generated by a local magnitude 9.0 full-margin earthquake of the Cascadia Subduction Zone (CSZ), and scenario two represents a tsunami triggered by a large earthquake on the Seattle Fault Zone (SFZ) of similar magnitude to the event that happened in 923 C.E. (magnitude ~7.5). These two modeled earthquake scenarios represent Washington's current "maximum considered" tsunami hazard from earthquakes either offshore in the CSZ or within Puget Sound in the upper plate of the Earth's crust. The tsunami generation from these CSZ and SFZ scenarios were also assessed regionally for all of Puget Sound by the Washington Geological Survey in 2021 (CSZ) and 2022 (SFZ), and have been adopted for preparedness, mitigation, response, and recovery planning statewide. Refer to both Dolcimascolo and others (2021) and Dolcimascolo and others (2022), respectively, for a greater geologic background and temporal history of each earthquake source, in addition to specific details of the earthquake scenarios used for the modeling of this maritime strategy. A distant tsunami generated within the Alaska-Aleutian subduction zone (AASZ) was initially considered as another scenario for this maritime study, however preliminary tsunami modeling suggested that a maximum considered scenario from this source provides negligible impact to Eagle Harbor. Therefore, this distant scenario was not pursued further for this strategy.

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

Study Area and Data Outline

The study area for this maritime assessment breaks into two boundary regions: 1) the Head of the Bay, and 2) the Mouth of the Bay. These regions overlap at the location of the Waterfront Park and City Dock (Figure 16). 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. All tsunami models were generated on 1/9th arc-second elevation grids and simulated for 12 and 3 hours respectively for the CSZ and SFZ scenarios. This site-specific modeling, which considers factors such as topography, bathymetry, and coastal dynamics, is vital to the assessment of potential tsunami impacts on critical maritime infrastructures. Through comprehensive analysis and simulation, the study aims to inform the development of effective mitigation measures, emergency response plans, and long-term strategies to safeguard the City of Bainbridge Island's Eagle Harbor and its maritime community against the threat of tsunamis.

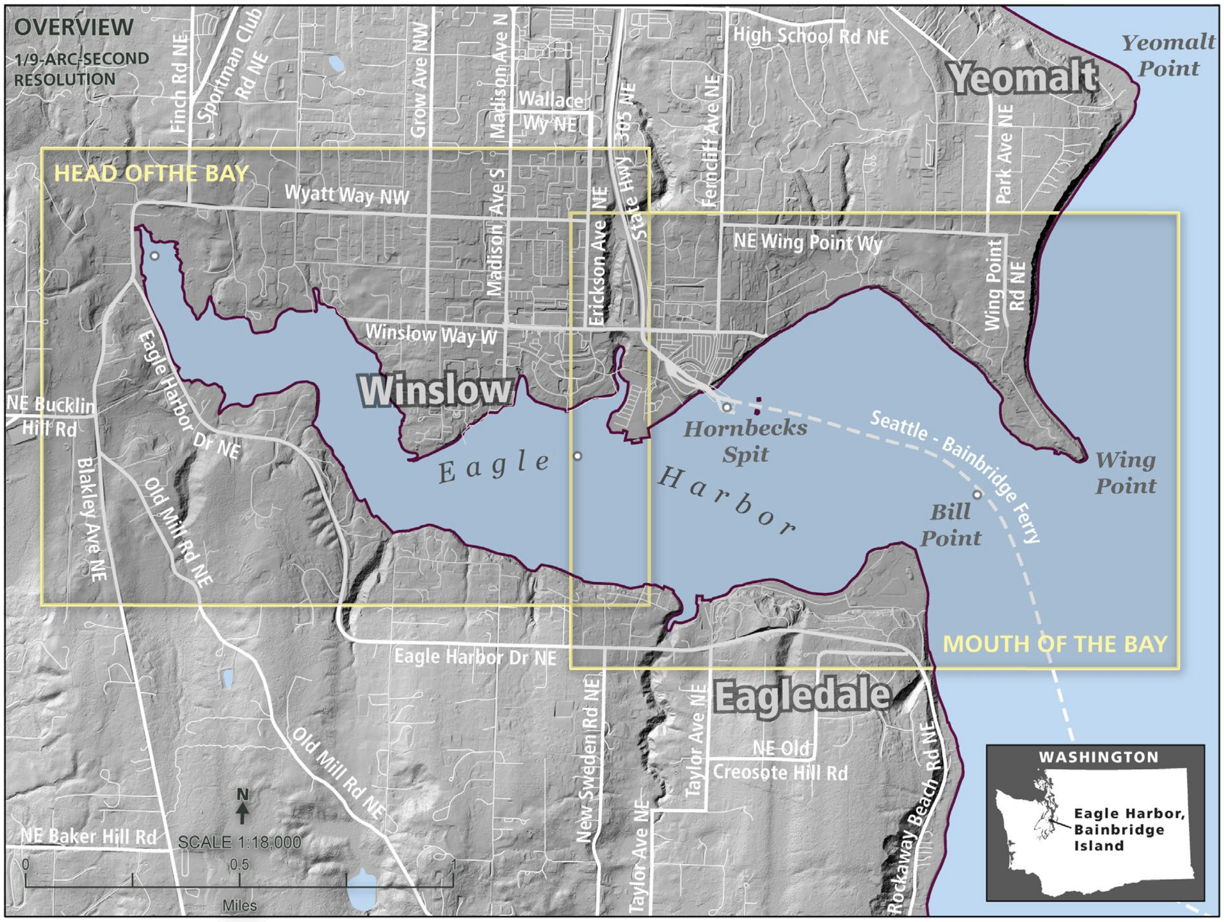


Figure 16: Study area of Bainbridge Island's, Eagle Harbor Tsunami Maritime Response and Mitigation Strategy. White dots within the waterway represent the selected locations of synthetic tide gauges included in this study.

Maximum Onshore Tsunami Inundation

Potential tsunami inundation (tsunami-induced flooding over previously dry land) poses significant risk to much of the built-up infrastructure in Eagle Harbor. 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.

Cascadia Subduction Zone

When simulating the CSZ earthquake scenario, the ensuing modeled tsunami mainly inundates the Eagle Harbor shoreline. In the low-lying areas along the Head of the Bay (Figure 17), inundation depths range from 3-9 feet, depending on the local topography. A maximum offshore wave height of ~7 feet is expected and occurs on the second wave peak based on the modeled simulations. Additionally, at Hawley Cove and Wing Point (Figure 18), inundation depths range from 2-5 feet, with an offshore wave height of ~4 feet for both the first and second wave peaks. The first wave peak enters Eagle Harbor at ~2 hours and 20 minutes and follows an initial wave trough, or water receding away from shore.

People near the shoreline and boaters on the water may still experience sloshing waves during and immediately after the earthquake shaking. This is referred to as a seiche; these specific seiche impacts were out of the scope of this study. If able, boaters and marina staff should dock and head to high ground immediately after the shaking stops and is safe to do so. Given the response time available, boaters may be inclined to take their vessels offshore in the event of a CSZ-type earthquake as deep water (greater than 100 fathoms) exists nearby within central Puget Sound. However, messaging should emphasize evacuation as the best protective action as the source of the earthquake shaking will not be immediately obvious to local decision makers nor members of the public. This is especially important given additional challenges boaters may encounter while on the water for an extended period, such as damage from contact with debris or other vessels caused by navigational difficulties created by the tsunami, hazardous materials exposure, and uncertainty in the operability of surrounding harbors and marinas.

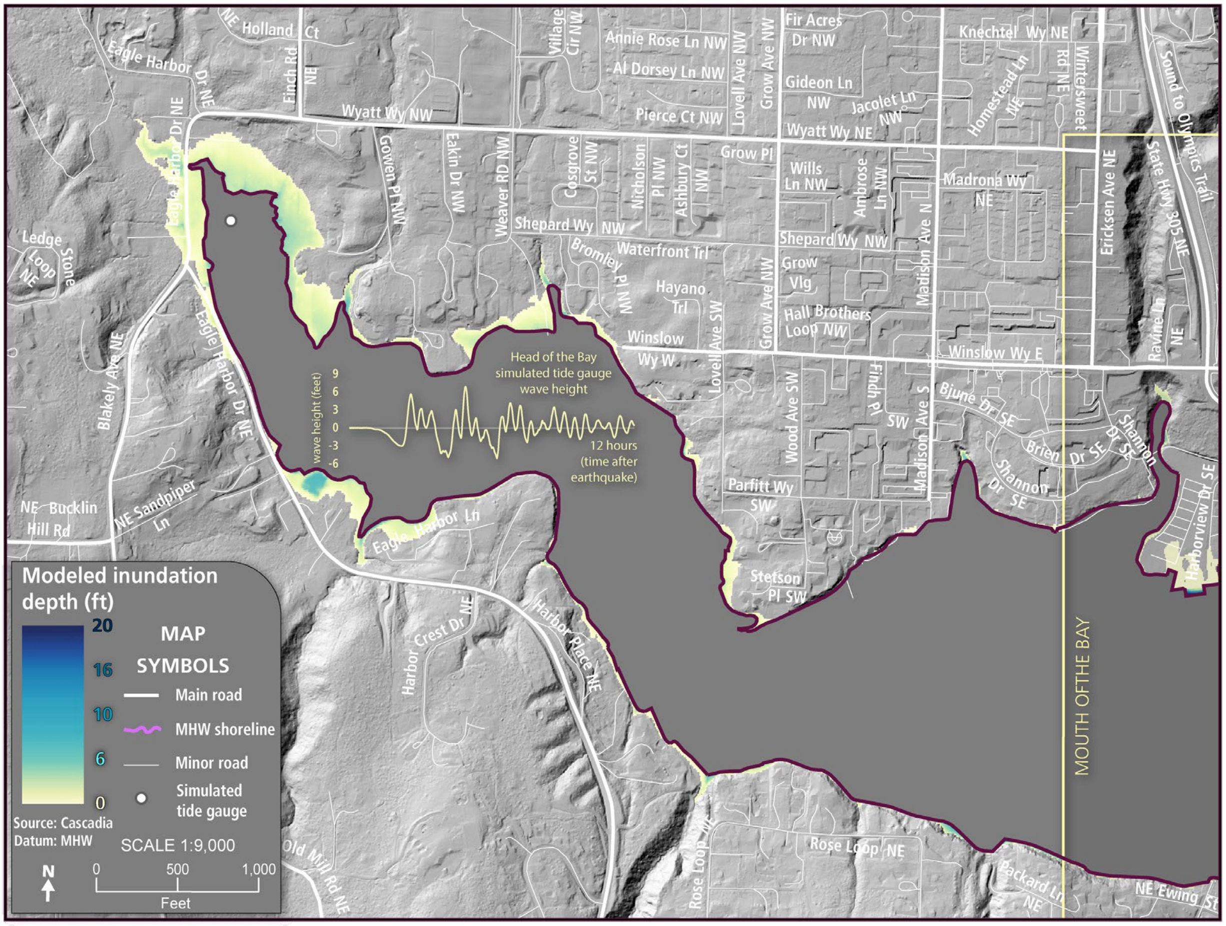


Figure 17: Modeled maximum tsunami inundation depths over land within the Head of the Bay boundary area from the Cascadia Subduction Zone (CSZ) earthquake scenario. Offshore tsunami wave heights within the head of the bay approach ~7 feet. Onshore flooding is generally confined within low-lying wetlands near the shoreline and range from ~3-9 feet. Tidal datum: Mean High Water. Model resolution: 1/9th arc-second (~3 meters).

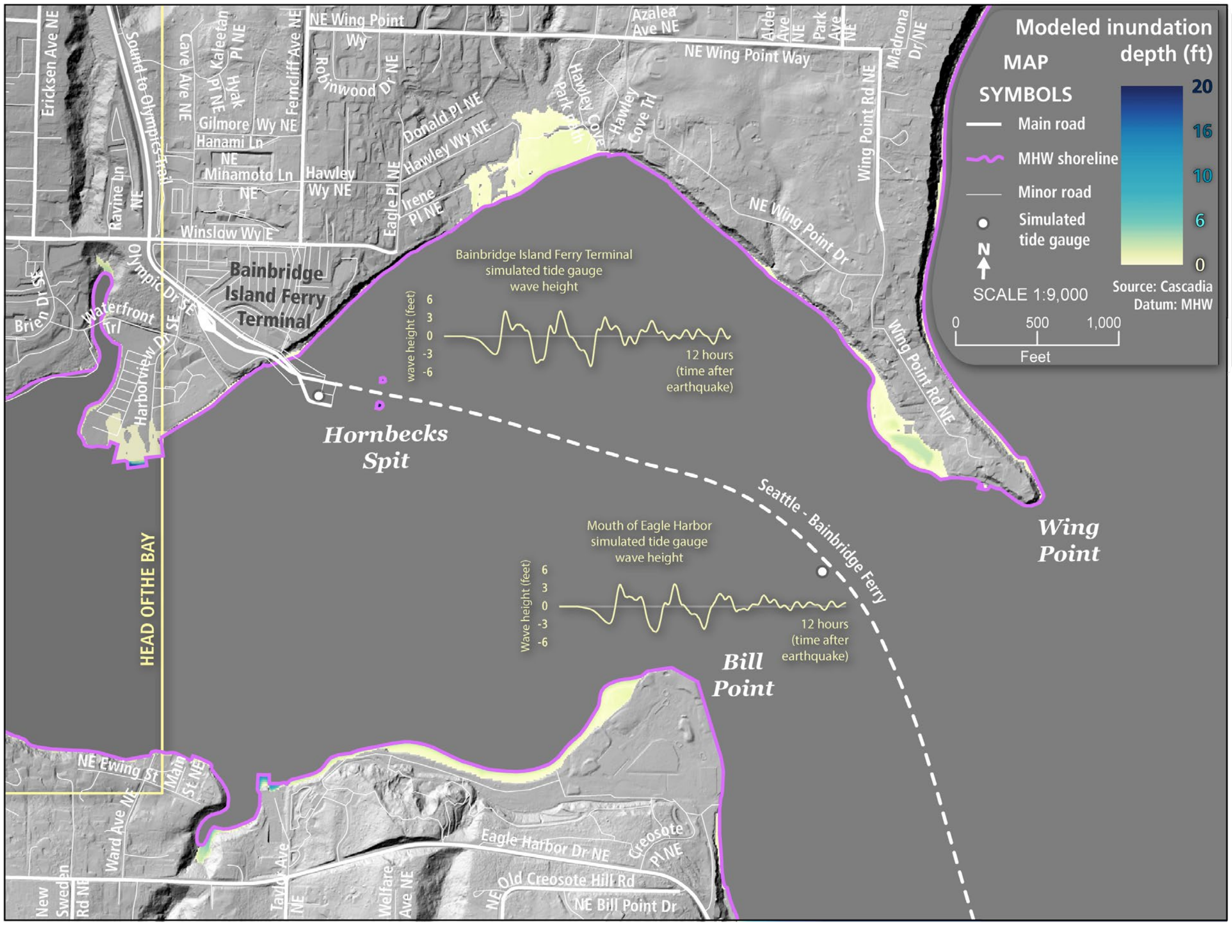


Figure 18: Modeled maximum tsunami inundation depths over land within the Mouth of the Bay boundary area from the Cascadia Subduction Zone (CSZ) earthquake scenario. Offshore tsunami wave heights approach 4 feet and onshore flooding depths generally range from a foot or less to 2-5 feet near Wing Point and Hawley Cove. Note the immediate shoreline of the Ferry Maintenance Yard may see increased flooding on the order of 13-16 feet. Tidal datum: Mean High Water. Model resolution: 1/9th arc-second (~3 meters).

Seattle Fault Zone (SFZ)

Inundation within Eagle Harbor is a major concern in the modeled Seattle Fault Zone (SFZ) scenario. In the Head of the Bay boundary region tsunami flooding depths are greater than 20 feet closest to the shoreline and extend beyond Eagle Harbor Dr NE (Figure 19). The maximum modeled offshore wave heights approach 23 feet and arrive in less than 20 minutes. Additionally, flooding depths between 16-20 feet and ~13 feet at the City Dock and Ferry Terminal Maintenance Yard, respectively, as shown in the Mouth of the Bay boundary area (Figure 20). Maximum offshore wave heights may also approach 16 feet near the Bainbridge Island Ferry Terminal, and 19 feet at Eagle Harbor's entrance. Wave heights this large would likely overtop pilings at certain docks, leaving infrastructure and moored vessels at risk to overturning, capsizing, collisions or washing onshore. A significant amount of debris would be picked up by the tsunami waves and may cause immense damage to existing maritime infrastructure.

The reported inundation values incorporate and are exacerbated by the impacts of coseismic subsidence (the sinking of land during the earthquake shaking) from the modeled SFZ scenario (Figure 21). In this scenario, all of Eagle Harbor drops ~5.5 feet. This estimated amount of subsidence is based on observed land level changes from the 923 C.E. Seattle Fault Zone event, where Restoration Point uplifted ~23 feet, Alki Point uplifted ~10 feet, and West Point, Seattle subsided ~3 feet. Subsidence of this scale would have major short- and long-term implications in recovery operations following the tsunami; the coastline would be permanently altered and areas near the shoreline could be lost to the new daily tidal range due to a potentially higher relative sea-level following the earthquake.

Response time in a SFZ tsunami event will also be extremely limited. It is expected that shaking from the earthquake may last from 1-2 minutes and tsunami inundation would start to impact the entirety of the Eagle Harbor shoreline in less than 10 minutes from the start of the earthquake shaking. Given the short response time for wave arrival and the estimated wave heights, boat owners onshore should immediately head to high ground once the shaking stops and conditions are safe to do so. It would not be feasible for boat owners within Eagle Harbor to attempt to take their boat out to deeper water in a SFZ tsunami event.

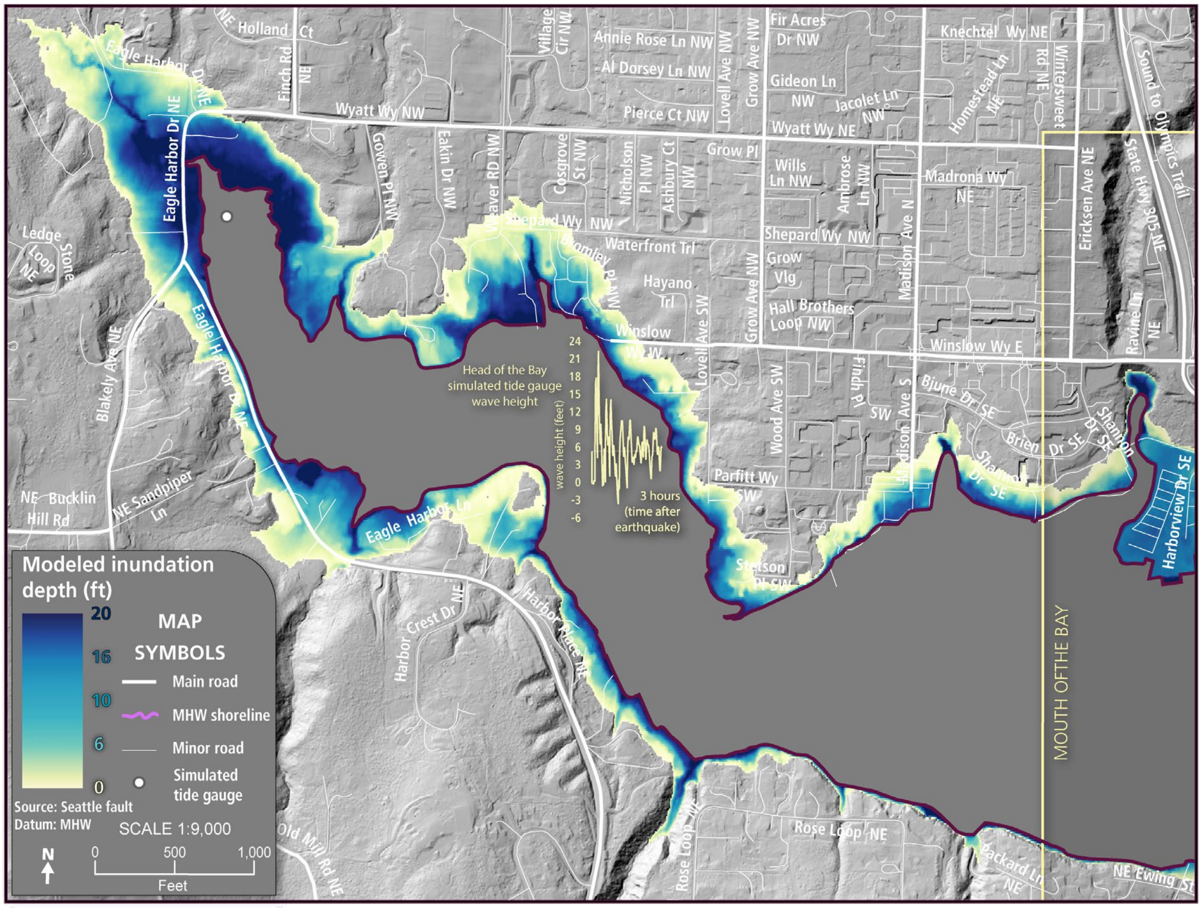


Figure 19: Modeled maximum tsunami inundation depths over land within the Head of the Bay boundary area from the Seattle fault earthquake scenario. Offshore tsunami wave heights approach 23 feet in just ~16-17 minutes. Onshore flooding is extensive beyond just shoreline locations and eclipses 20 feet (darkest blue) in many areas. Depths of flooding decrease moving away from the shoreline. Tidal datum: Mean High Water. Model resolution: 1/9th arc-second (~3 meters).

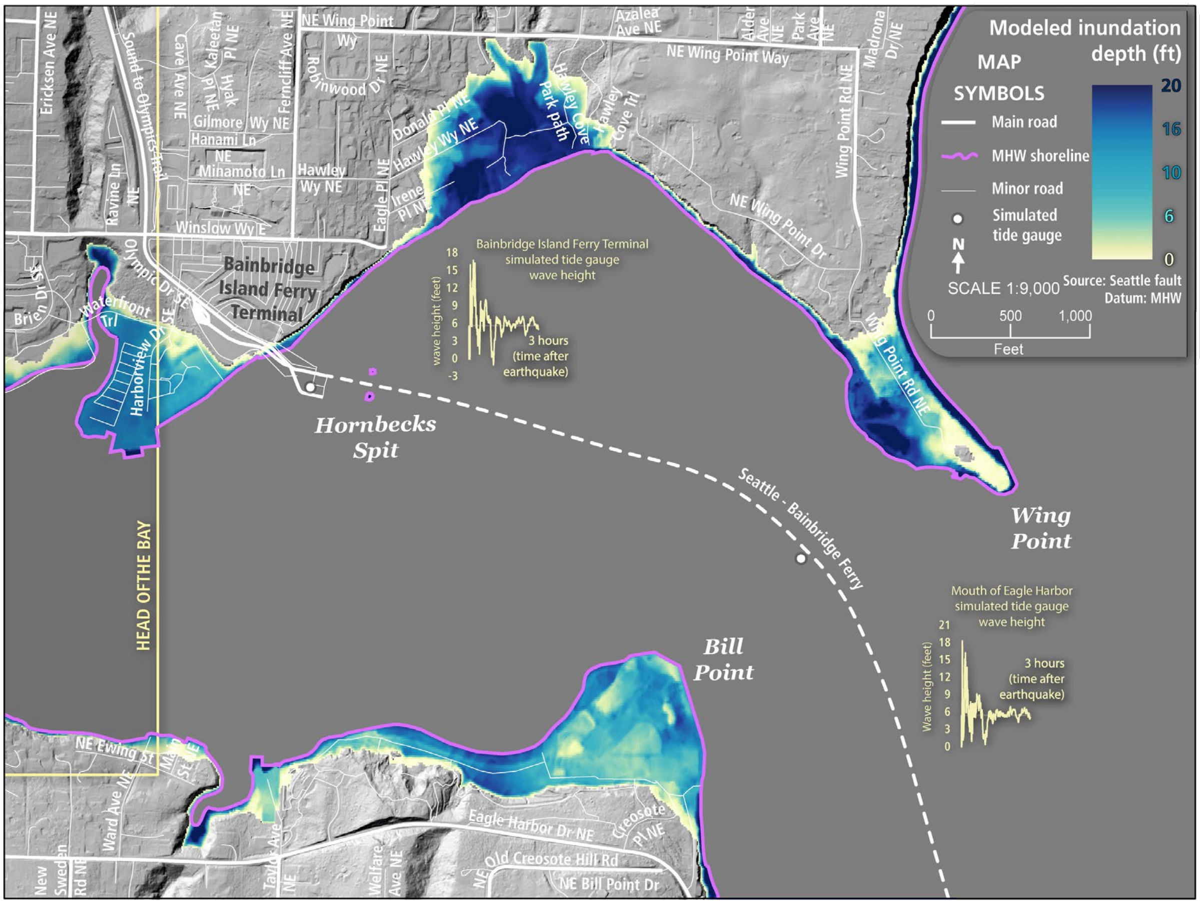


Figure 20. Modeled maximum tsunami inundation depths over land within the Mouth of the Bay boundary area from the Seattle fault earthquake scenario. Offshore tsunami wave heights approach 16 feet near the Bainbridge Island Ferry Terminal and 19 feet at the entrance into Eagle Harbor. Onshore flooding depths range from 16-20 feet near the City Dock and ~13 feet at the Ferry Terminal Maintenance Yard. Tidal datum: Mean High Water. Model resolution: 1/9th arc-second (~3 meters).

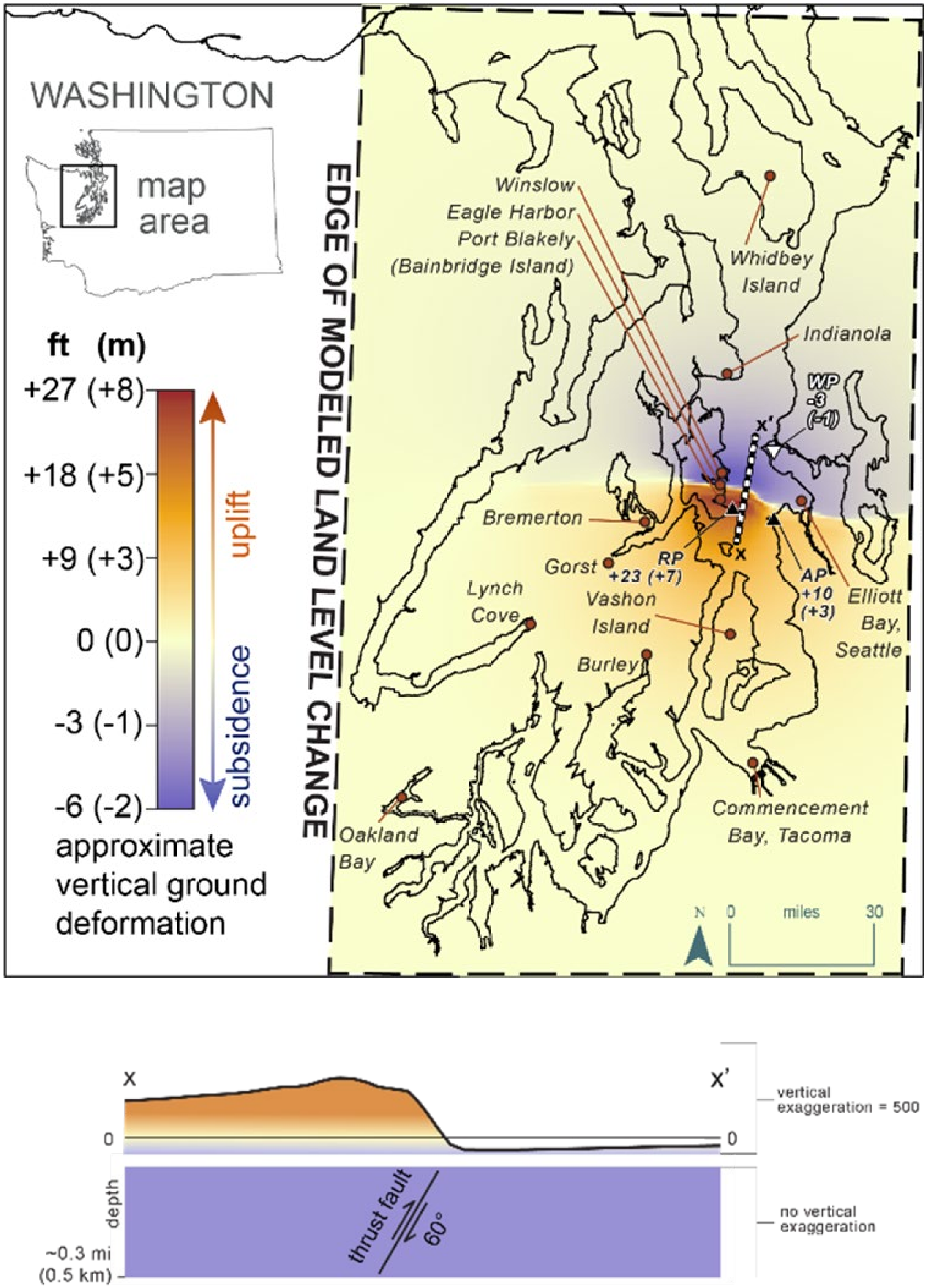


Figure 21: Top) Land level change from the modeled Seattle fault earthquake scenario, which reproduces observed surface deformation from the 923 C.E. Seattle fault event at Alki Point (AP; 10 feet), Restoration Point (RP; +23 feet), and West Point (WP; - 3 feet). Bottom) Thrust fault model diagram corresponding to the X—X' line crossing the modeled Seattle fault rupture.

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 are the result of tsunami forces and do not represent pre-existing 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, current speeds were binned into four ranges: 0–3 knots, 3–6 knots, 6–9 knots, and >9 knots. These ranges generally follow the port damage categorization of Lynett and others (2014) that approximates hazards to ships and docking facilities. Speeds ranging from 0-3 knots represent no expected damage, 3-6 knots represent minor/moderate damage possible, 6-9 knots represent major damage possible, and speeds greater than 9 knots represent extreme damage possible. Note that these 3-6-9 knot expected damage thresholds tend to be accurate for newer (less than 30-40 years old) and well-maintained docks and harbor infrastructure. For older (greater than 40-50 years old) and less maintained docks, thresholds of 2-5-7 knots may be more appropriate to predict potential 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 throughout the duration of the tsunami at either Mean High Water or Mean Low Water.

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

Cascadia Subduction Zone

Modeled current speeds from the CSZ scenario do not locally exceed 9 knots, the maximum categorization, except for a small area offshore the spit of Williamson Landing Marina in the Head of the Bay boundary area (Figure 22). The general speeds within the Head of the Bay are 6 knots or less. Docks located within the higher end of these projections could still expect minor to moderate amounts of damage, depending on their age, how they were engineered, and how they are maintained. Areas with maximum current speeds between 0-3 knots are not expected to receive significant damage, though small objects such as buoys may be displaced.

Furthermore, in the Mouth of the Bay map boundary, speeds near the City Dock, Ferry Terminal, and Ferry Terminal Maintenance Yard are less than three knots and would likely not be impacted from the increased current speeds (Figure 23). On the eastern side of Eagle Harbor, the mouth of Eagle Harbor, such as offshore Wing Point and Bill Point, modeled current speeds increase into the 3-6 knot range and create more hazardous conditions for boaters and may cause minor to moderate damage to any infrastructure. Even at these speeds, whirlpools, eddies, and sudden current changes may be present, which increases the potential hazards for boaters. It is not recommended to navigate or remain on the water during these tsunami conditions as collisions with other vessels or debris could result in heavy damage to boats of any size and is a risk to life safety.

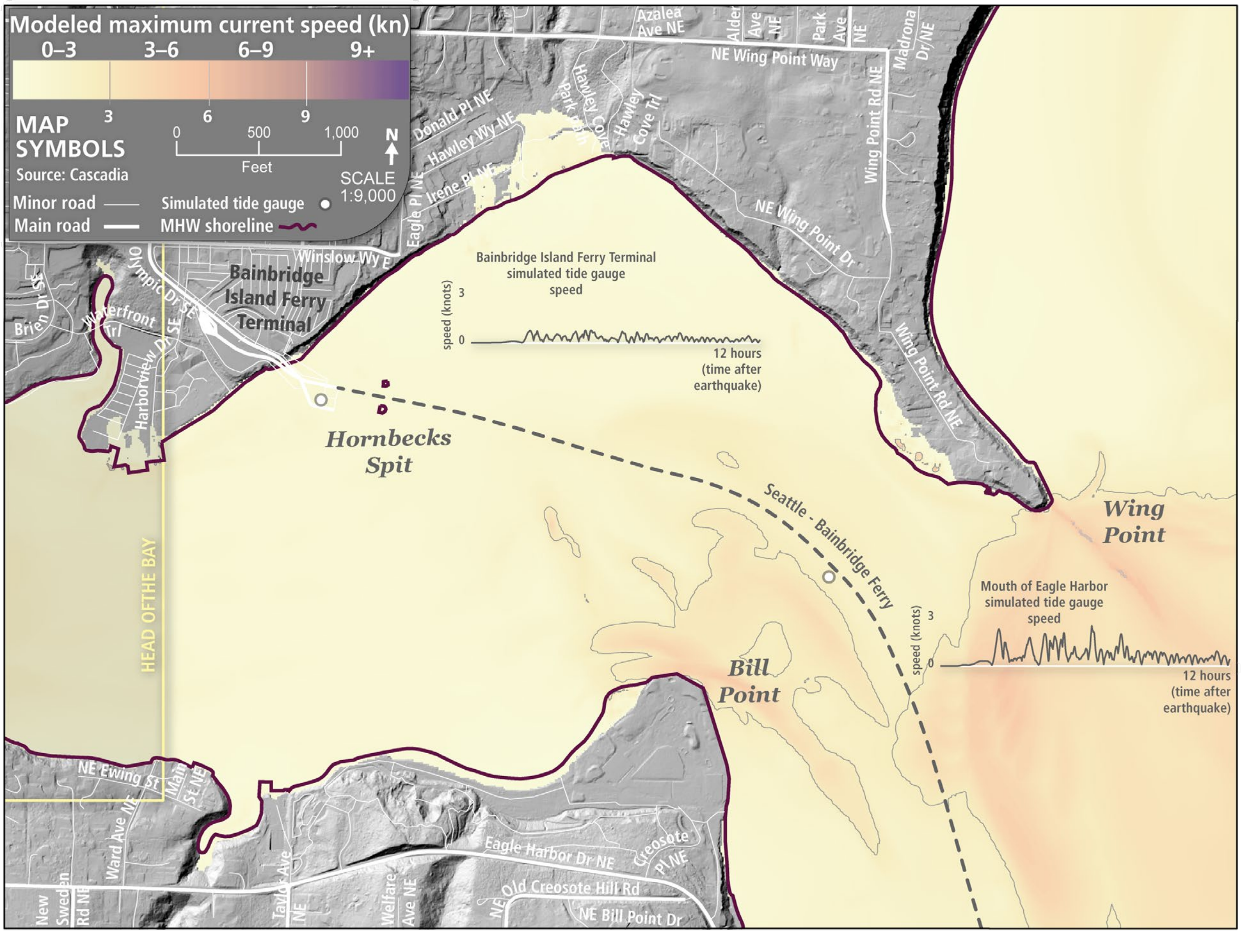


Figure 22: Modeled tsunami current speeds within the Head of the Bay boundary area from the Cascadia subduction zone earthquake scenario. Tidal datum: maximum values generated between the Mean High Water and Mean Low Water runs. Model resolution: 1/9th arc-second (3 m).

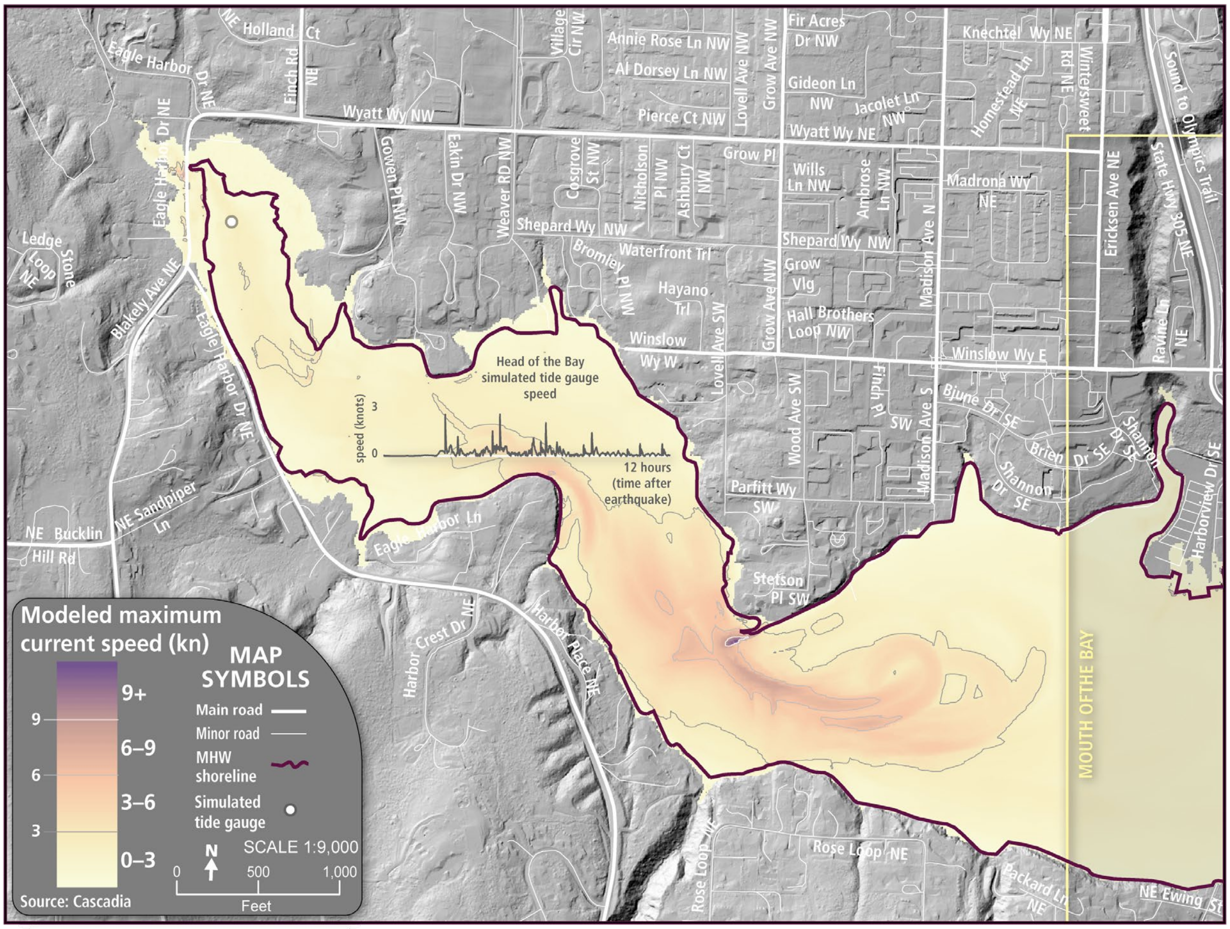


Figure 23: Modeled tsunami current speeds within the Mouth of the Bay boundary area from the Cascadia subduction zone earthquake scenario. Tidal datum: maximum values generated between the Mean High Water and Mean Low Water runs. Model resolution: 1/9th arc-second (3 m).

Seattle Fault Zone

The modeled Seattle Fault Zone (SFZ) scenario presents significant risks to infrastructure and boaters throughout the entirety of Eagle Harbor. In all locations, the maximum current speeds arrive quickly in less than 10 minutes and are generally much greater than the 6-knot damage threshold (Figures 24, 25). In the Head of the Bay boundary map, maximum tsunami current speeds exceed 9 knots almost everywhere. With current speeds exceeding 9 knots above normal, major damage is expected to all maritime infrastructure and large vessels and may result in complete destruction of infrastructure and vessels in the area. There will be widespread debris in the aftermath spread throughout Eagle Harbor.

The waterway will be extremely dangerous for boaters caught in the water as rapid water-level changes, whirlpools and eddies will cause sudden current changes and create significant challenges in trying to navigate. Of note in the modeled simulations, a whirlpool is generated just South of the Williamson Landing Marina and moves in the northeast direction towards the City Dock between 19 and 28 minutes following the main inundating wave peak. To generalize the overall current speeds from the SFZ scenarios, speeds are greatest west of the City Dock and at the entrance to Eagle Harbor offshore Wing Point and Pritchard Park. The tsunami modeling also suggests that speeds are fastest near shorelines and slowest in the center of the harbor, such as between Harbor Marina and the ferry terminal maintenance yard where pockets of ~4-6 knot currents exist. The fastest currents were often recorded during the trough phase of the tsunami, when water is pulling away from shore. As a boat owner, the best course of action is to move inland to high ground immediately after the shaking stops given the extremely limited time before the tsunami impacts the area.

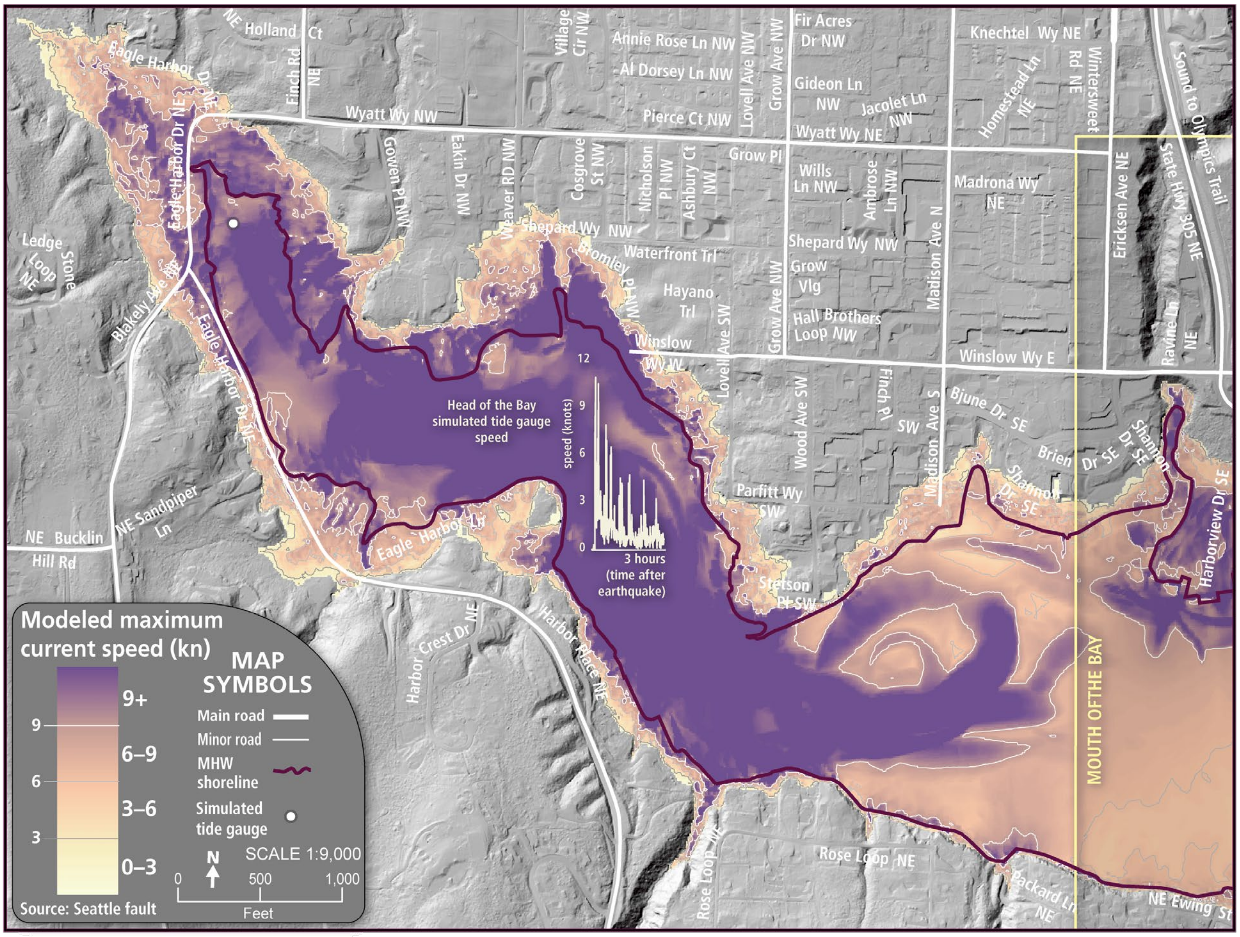


Figure 24: Modeled tsunami current speeds within the Head of the Bay boundary area from the Seattle Fault Zone (SFZ) earthquake scenario. Tidal datum: maximum values generated between the Mean High Water and Mean Low Water runs. Model resolution: 1/9th arc-second (3 m).

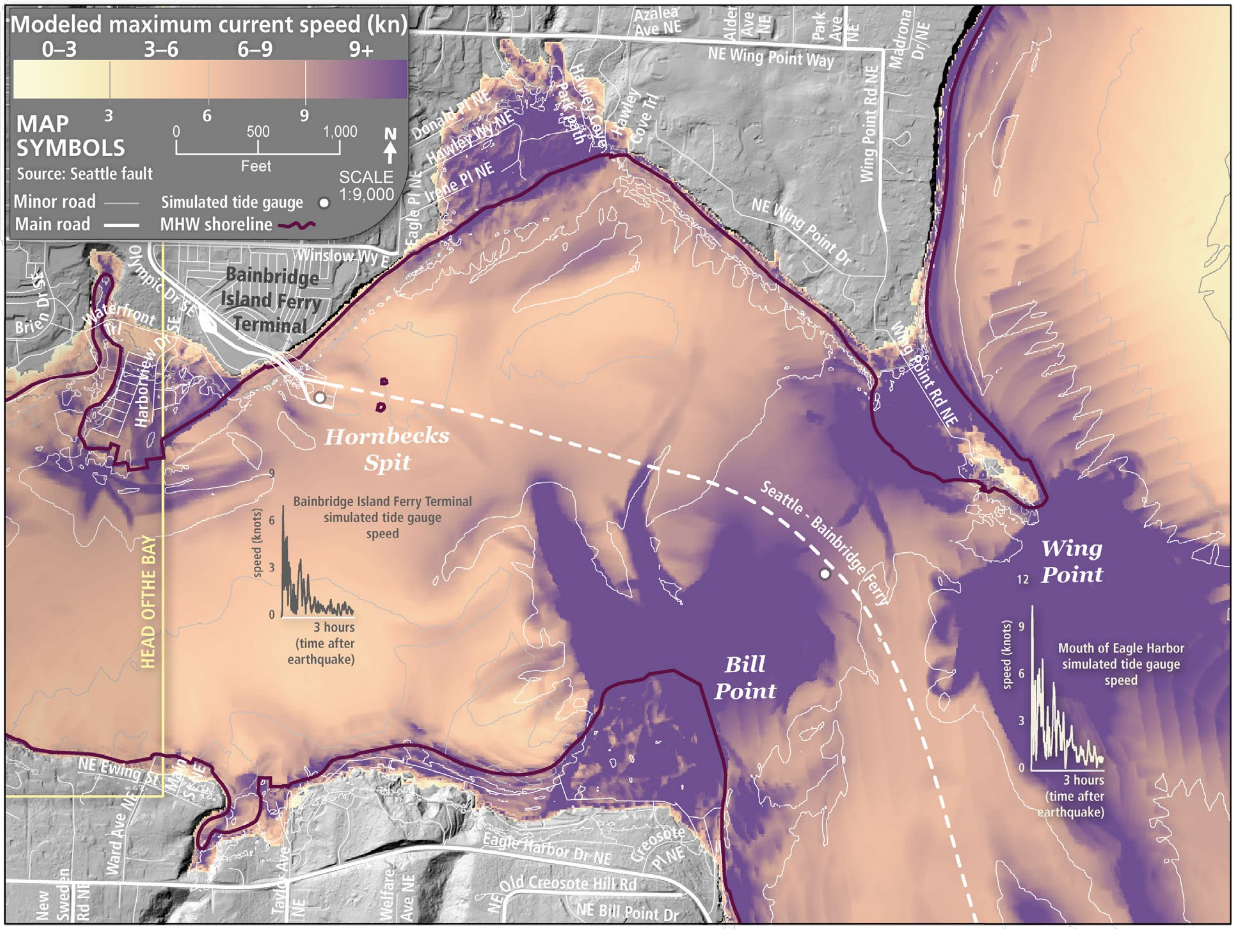


Figure 25: Modeled tsunami current speeds within the Mouth of the Bay boundary area from the Seattle Fault Zone (SFZ) earthquake scenario. Tidal datum: maximum values generated between the Mean High Water and Mean Low Water runs. Model resolution: 1/9th arc-second (3 m).

Minimum Water Depth

The minimum water depths, or drawdown, modeled for both the Cascadia Subduction Zone (CSZ) and Seattle Fault Zone (SFZ) tsunami scenarios highlight significant risks to boaters and vessels. As the water recedes during the trough of the tsunami, shallow areas could leave vessels grounded, making them immobile until the next rising wave. Any attempt to board vessels during this period would be dangerous, and boats trying to navigate away could be damaged if they encounter water that is too shallow. Boats may even capsize with the next rising wave and receive significant damage from the wave. The drawdown process, which can expose large areas of the seafloor, also poses risks of rapid dragging and scouring from sediment shifts, which could cause damage to both vessels and infrastructure.

These minimum water depths provide essential information for assessing where vessels with shorter draft distances should avoid mooring and highlight areas that may need future dredging to reduce the risk of grounding. Figures 26 and 27 illustrate the CSZ scenario, and Figures 28 and 29 show the SFZ scenario, all based on low tide conditions for a more conservative estimate.

Modeled results show that the CSZ scenario produced slightly greater drawdown in certain parts of Eagle Harbor than the SFZ scenario. The differences are primarily represented in Eagle Harbor's Head of the Bay, and at Eagle Harbor's Mouth near Wing Point and Pritchard Park. These differences are likely results of 1) the CSZ earthquake source generating a longer tsunami wavelength than the SFZ earthquake source, and 2) the local subsidence that impacts the study area from the SFZ source. The modeled ~5.5 feet of subsidence diminish the overall impact of the trough-phase of the tsunami as local sea-level recovers and flows back into the subsided areas with the onset of the first inundating waves.

Cascadia Subduction Zone

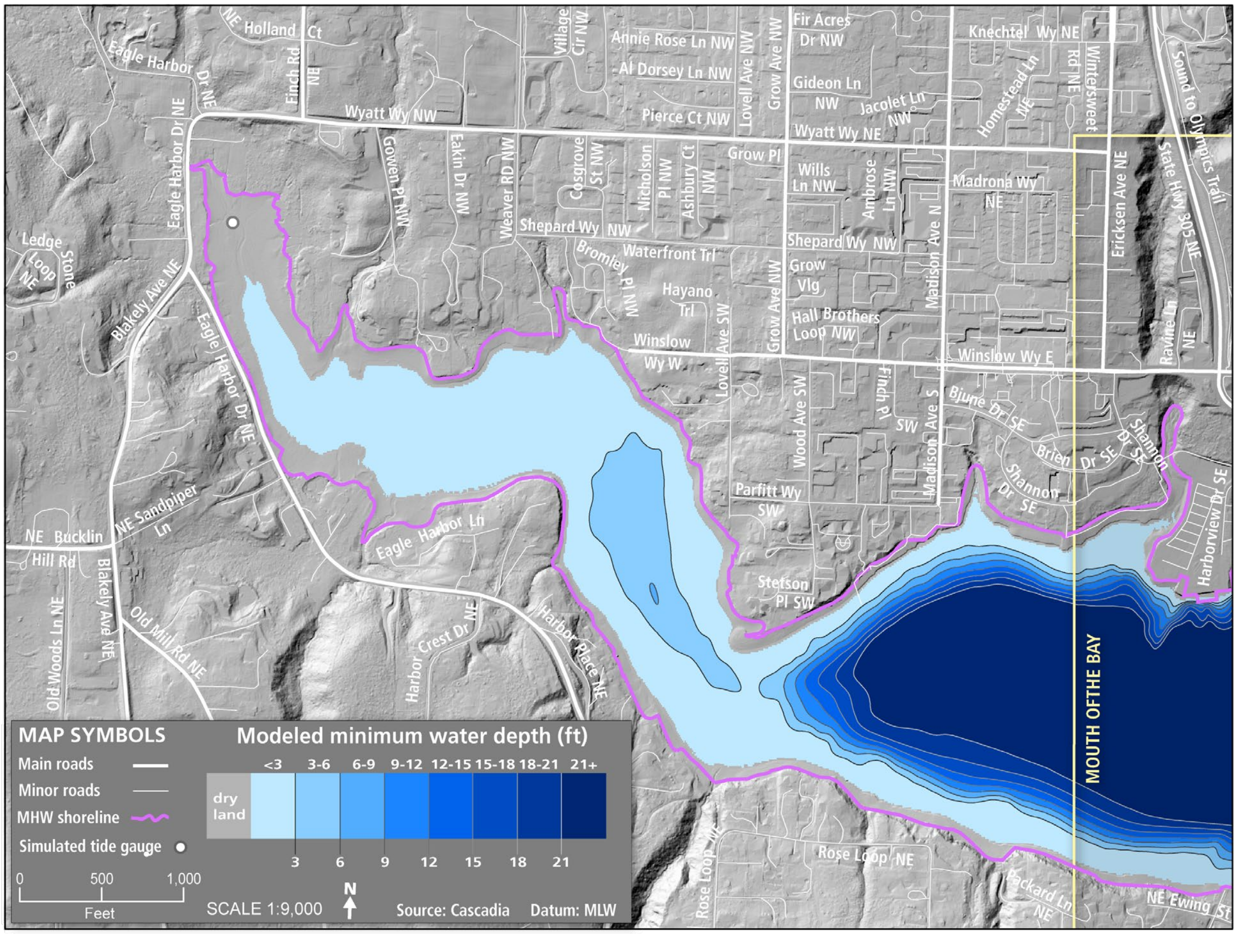


Figure 26: Modeled minimum water depths within the Head of the Bay boundary from the tsunami generated by the Cascadia Subduction Zone (CSZ) earthquake scenario. Tidal datum: Mean Low Water. Model resolution: 1/9th arc-second (3 m).

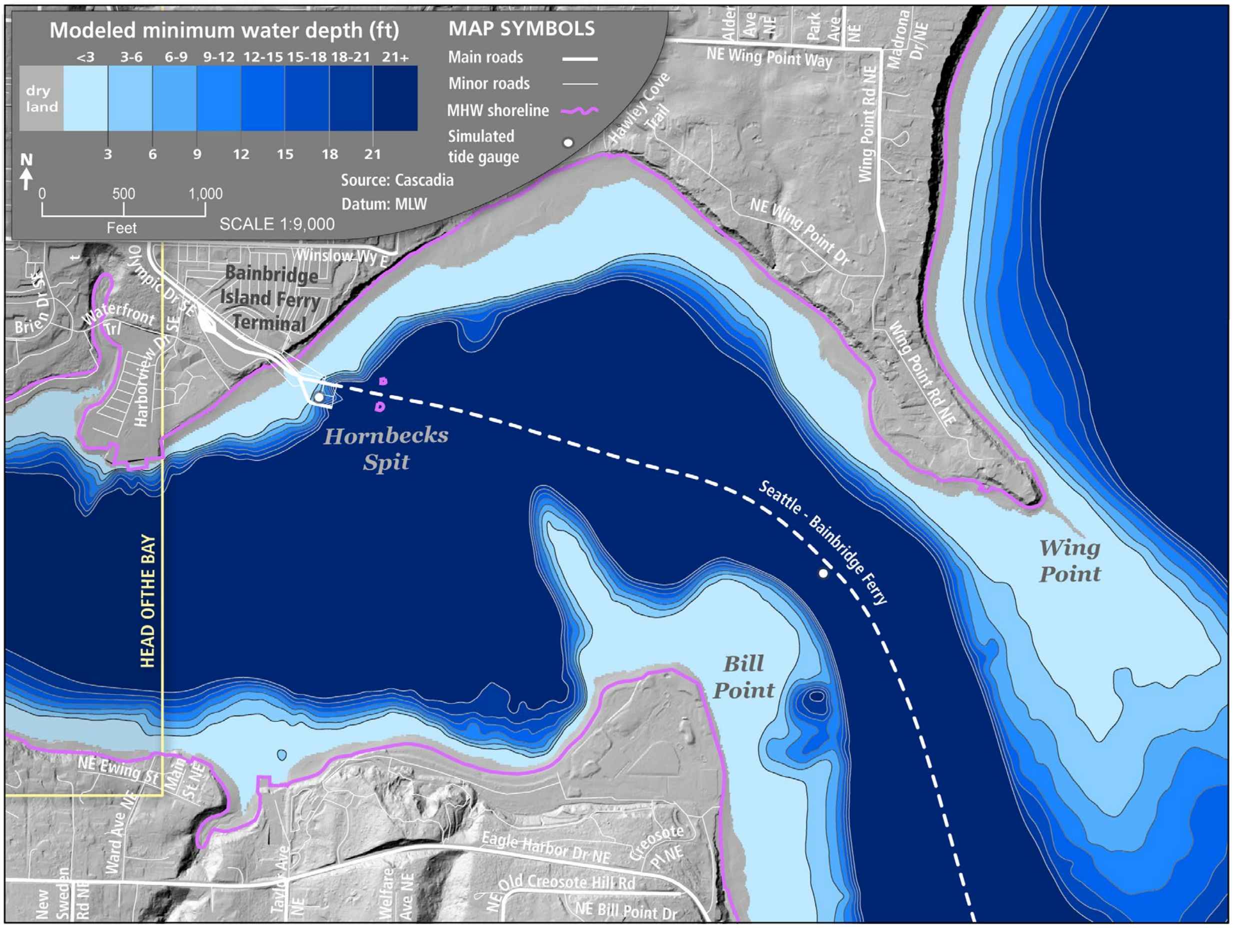


Figure 27: Modeled minimum water depths within the Mouth of the Bay boundary from the tsunami generated by the Cascadia Subduction Zone (CSZ) earthquake scenario. Tidal datum: Mean Low Water. Model resolution: 1/9th arc-second (3 m).

Seattle Fault Zone

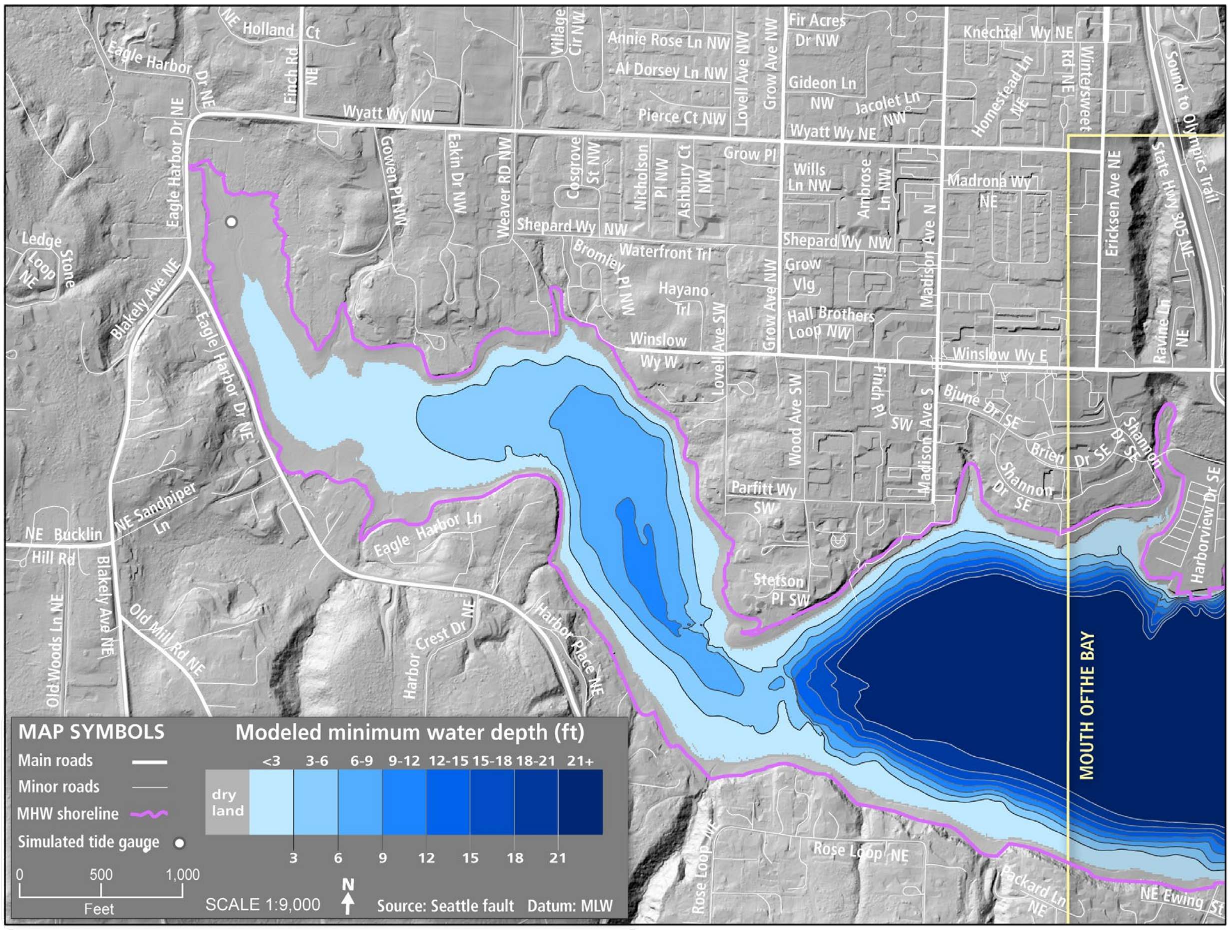


Figure 28: Modeled minimum water depths within the Head of the Bay boundary from the tsunami generated by the Seattle Fault Zone (SFZ) earthquake scenario. Tidal datum: Mean Low Water. Model resolution: 1/9th arc-second (3 m).

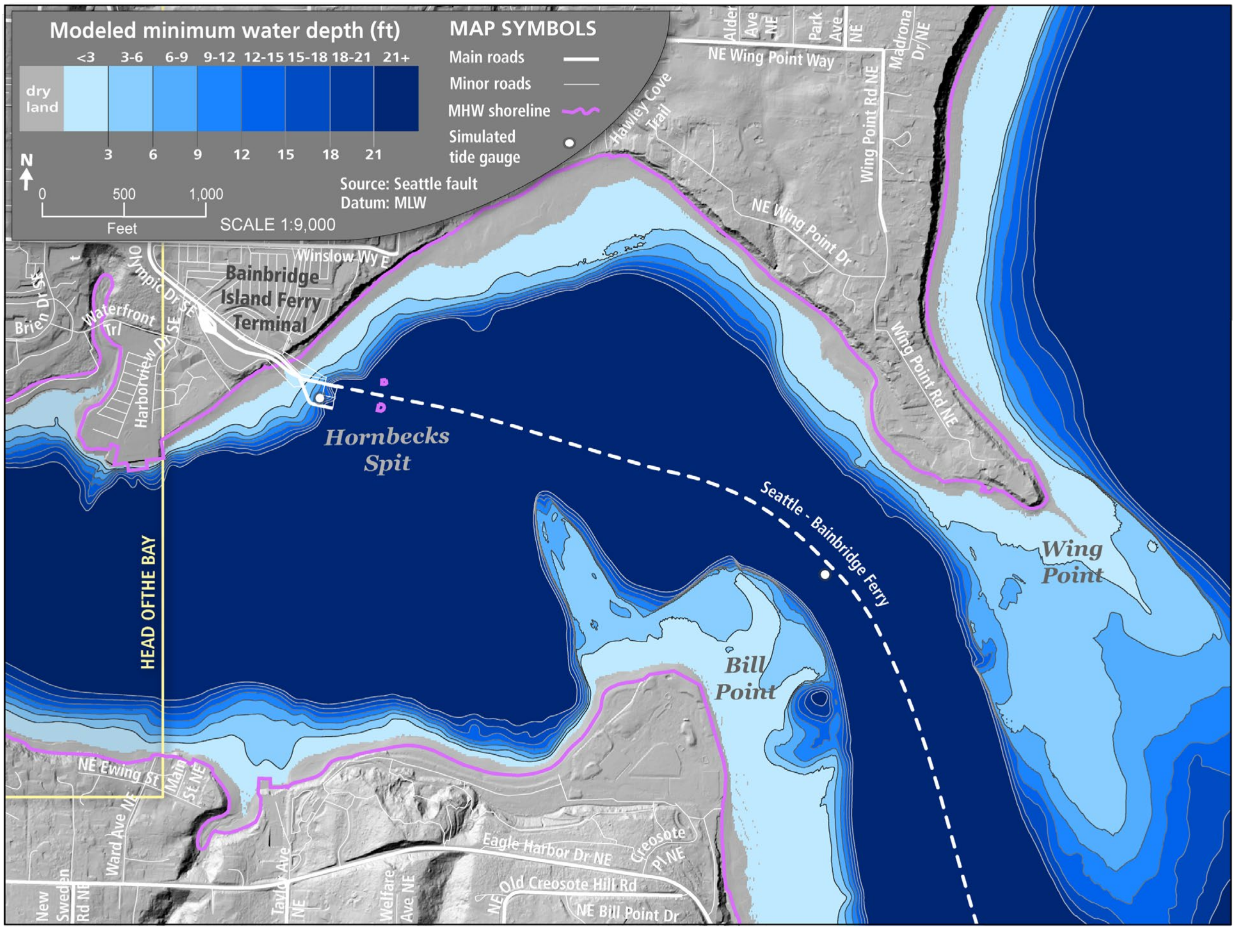


Figure 29: Modeled minimum water depths within the Mouth of the Bay boundary from the tsunami generated by the Seattle Fault Zone (SFZ) earthquake scenario. Tidal datum: Mean Low Water. Model resolution: 1/9th arc-second (3 m).

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 response and mitigation efforts, as they provide insights into when and how long maximum wave heights, drawdowns, and increased current speeds may occur during a tsunami.

In this study, each synthetic tide gauge records wave heights (Figures 30-33) and current speeds (Figures 34-37) over 12 simulated hours for the Cascadia Subduction Zone (CSZ) scenario and 3 simulated hours for the Seattle Fault Zone (SFZ) 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 just 12 and 3 hours, respectively for the CSZ and SFZ scenarios, real-world tsunami effects could last longer, and even minor waves or increased currents could delay response and recovery operations. For specific information on wave arrivals, summary tables (1 and 2) provide detailed timings at different wave height thresholds, including advisory and warning-level waves.

City Dock

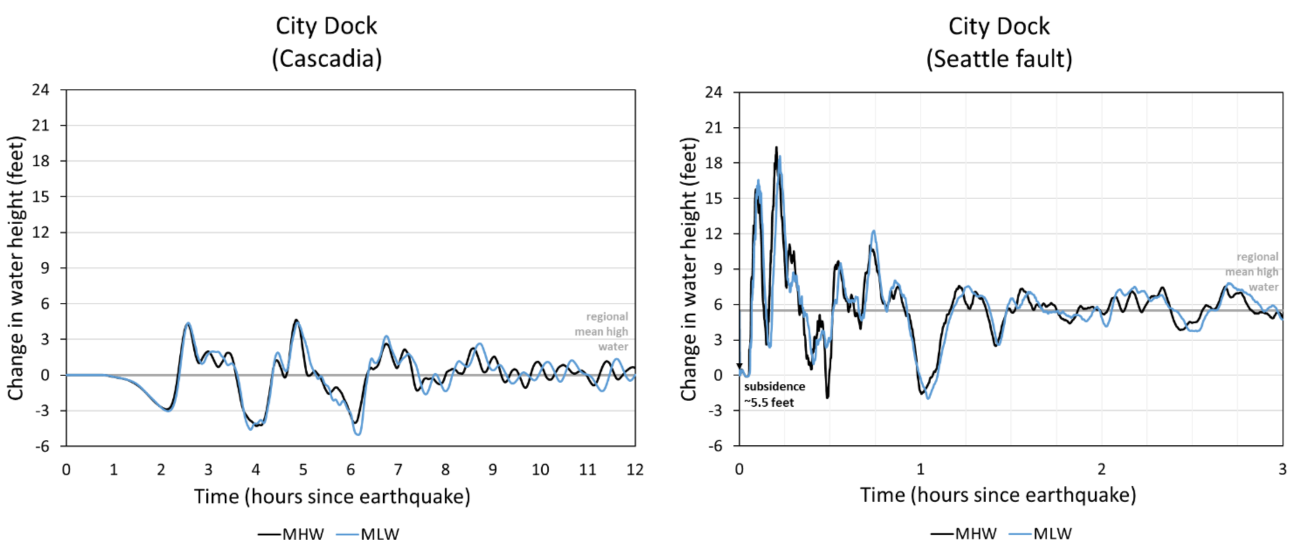


Figure 30: Modeled tsunami wave heights over time at the City Dock simulated synthetic tide gauge from the Cascadia Subduction Zone (CSZ, left) and Seattle Fault Zone (SFZ, right) earthquake scenarios. Water height '0' represents the post-earthquake elevation, accounting for subsidence in the Seattle fault scenario. Black and blue lines represent simulations using either the Mean High Water or Mean Low Water tidal datum, respectively.

Bainbridge Island Ferry Terminal

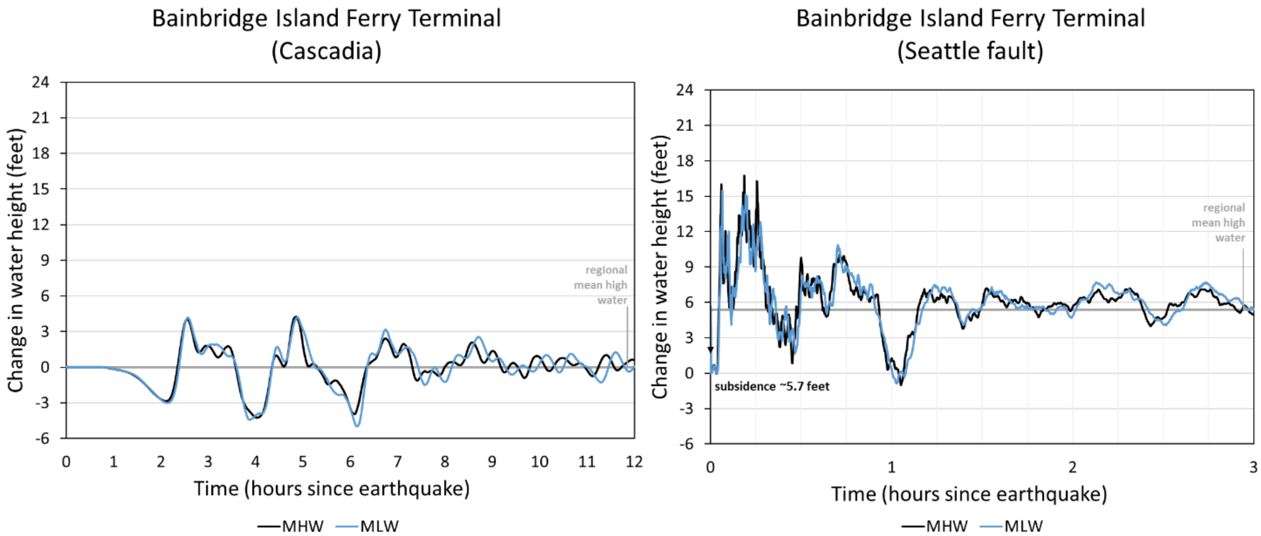


Figure 31: Modeled tsunami wave heights over time at the Bainbridge Island Ferry Terminal simulated synthetic tide gauge from the Cascadia Subduction Zone (CSZ, left) and Seattle Fault Zone (SFZ, right) earthquake scenarios. Water height '0' represents the post-earthquake elevation, accounting for subsidence in the Seattle fault scenario. Black and blue lines represent simulations using either the Mean High Water or Mean Low Water tidal datum, respectively.

Head of the Bay

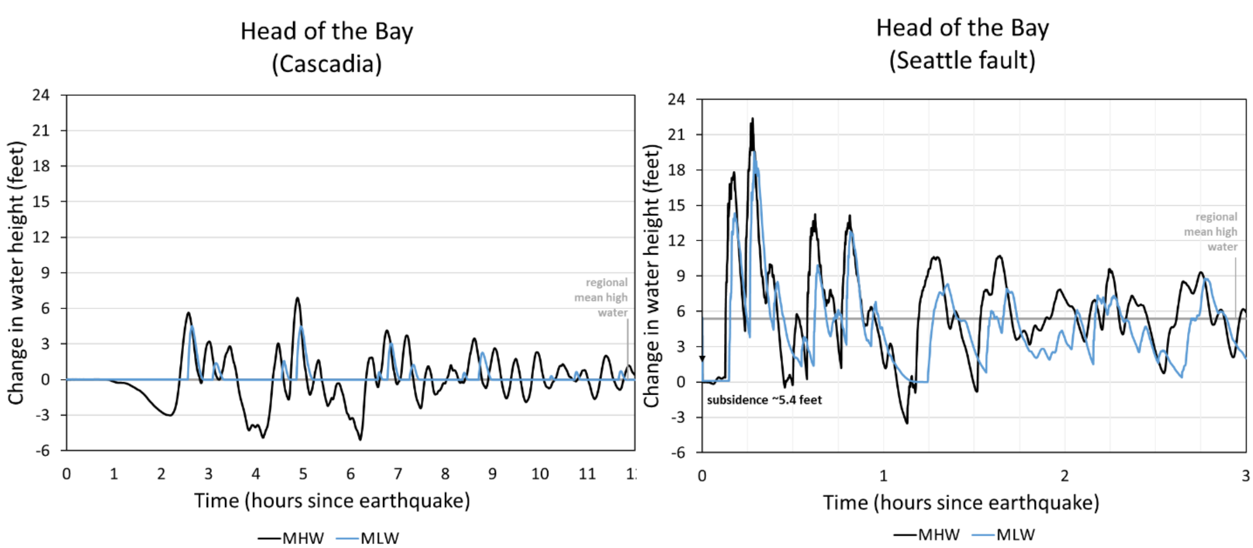
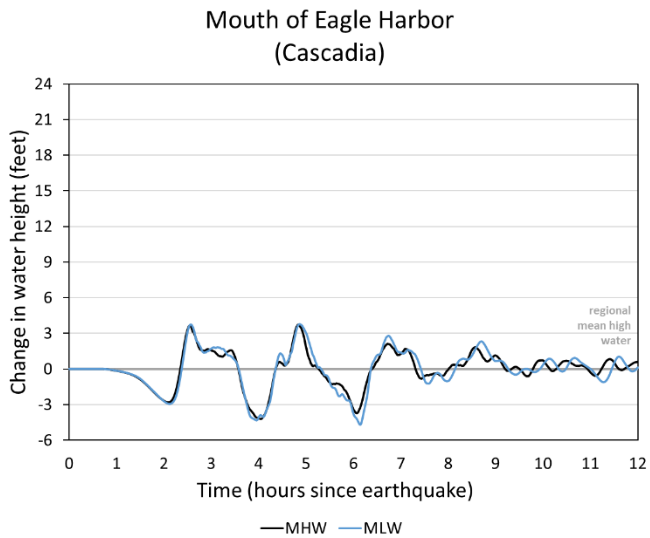


Figure 32: Modeled tsunami wave heights over time at the Head of the Bay simulated synthetic tide gauge from the Cascadia Subduction Zone (CSZ, left) and Seattle Fault Zone (SFZ, right) earthquake scenarios. Water height '0' represents the post-earthquake elevation, accounting for subsidence in the Seattle fault scenario. Black and blue lines represent simulations using either the Mean High Water or Mean Low Water tidal datum, respectively.

Mouth of Eagle Harbor



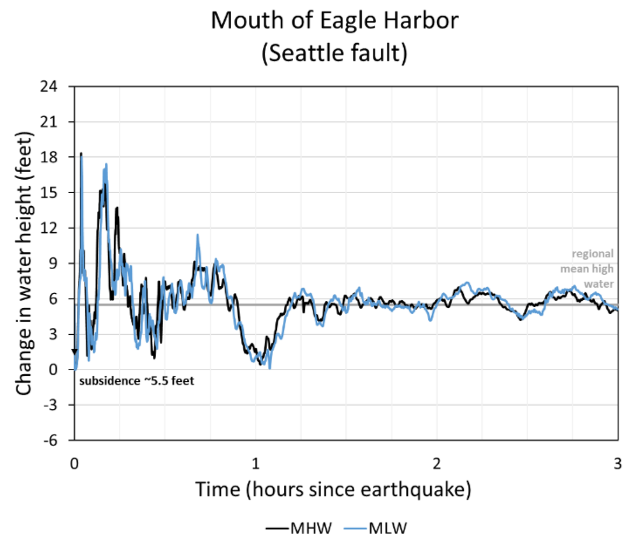


Figure 33: Modeled tsunami wave heights over time at the Mouth of Eagle Harbor simulated synthetic tide gauge from the Cascadia Subduction Zone (CSZ, left) and Seattle Fault Zone (SFZ, right) earthquake scenarios. Water height '0' represents the post-earthquake elevation, accounting for subsidence in the Seattle fault 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

City Dock

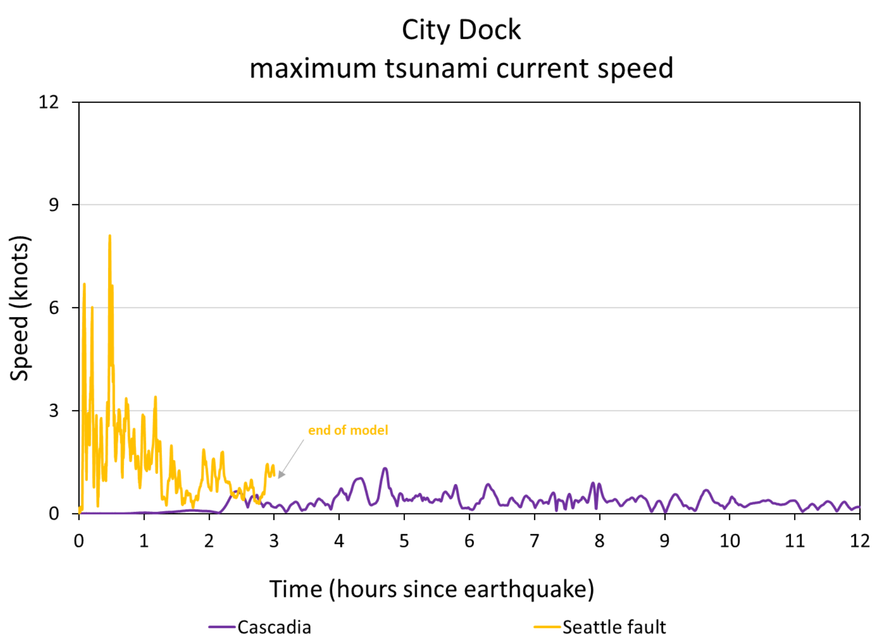


Figure 34: Modeled tsunami current speed over time at the City Dock simulated synthetic tide gauge. Purple and yellow lines represent simulations from the Cascadia and Seattle fault earthquake scenarios, respectively. Reported speeds are maximum values generated from either the mean high water or mean low water simulations.

Bainbridge Island Ferry Terminal

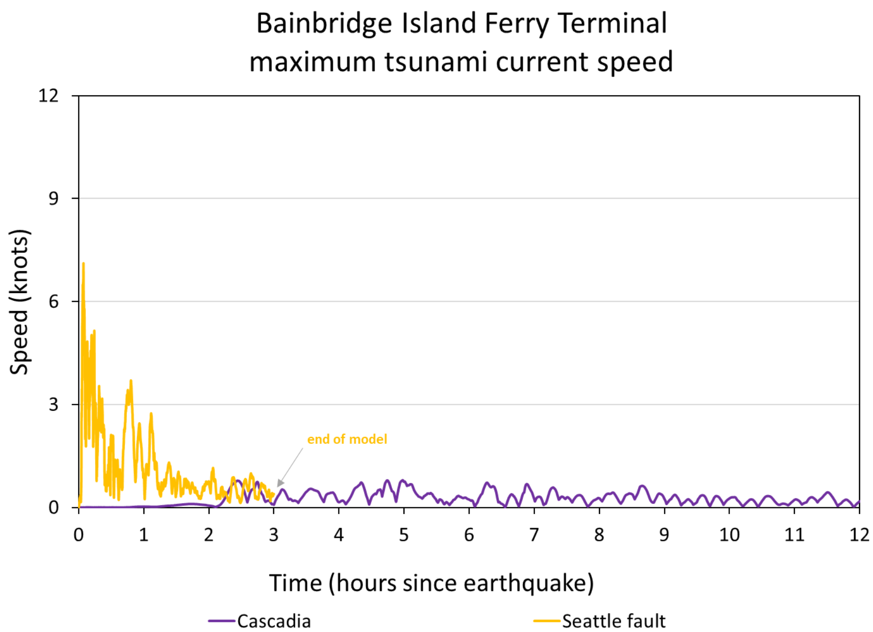


Figure 35: Modeled tsunami current speed over time at the Bainbridge Island Ferry Terminal simulated synthetic tide gauge. Purple and yellow lines represent simulations from the Cascadia and Seattle fault earthquake scenarios, respectively. Reported speeds are maximum values generated from either the mean high water or mean low water simulations.

Head of the Bay

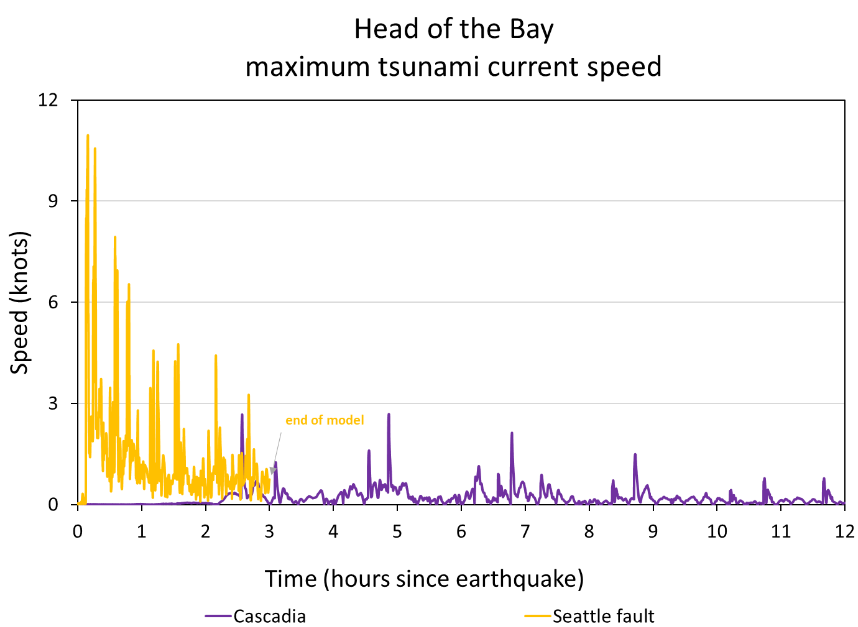


Figure 36: Modeled tsunami current speed over time at the Head of the Bay simulated synthetic tide gauge. Purple and yellow lines represent simulations from the Cascadia and Seattle fault earthquake scenarios, respectively. Reported speeds are maximum values generated from either the mean high water or mean low water simulations.

Mouth of Eagle Harbor

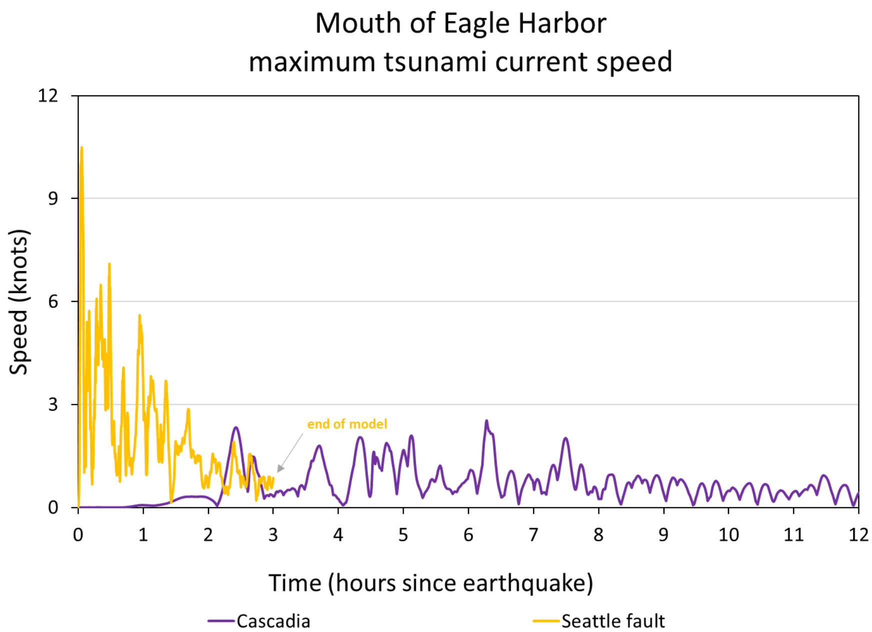


Figure 37: Modeled tsunami current speed over time at the Mouth of Eagle Harbor simulated synthetic tide gauge. Purple and yellow lines represent simulations from the Cascadia and Seattle fault earthquake scenarios, respectively. Reported speeds are maximum values generated from either the mean high water or mean low water simulations.

Wave Arrival Time Summary Tables

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

***TFirstAdvis (First Advisory)**:*

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

***TFirstDraw (First Drawdown)**:*

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

***TFirstWarn (First Warning)**:*

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

TMax (Maximum Wave Height):

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

TMin (Maximum Drawdown):

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

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.

Table 1. CSZ scenario, timing since start of earthquake (minutes)

Location	TFirst Advis	TFirst Draw	TFirst Warn	TMax	TMin
City Dock	143	93	148	291	369
Head of the bay*	145	94	148	292	372
Mouth of Eagle Harbor	143	93	149	290	368
Ferry terminal	143	93	148	291	368

* Initializes as dry land in Mean Low Water simulation.

Seattle Fault Zone (SFZ)

Table 2 shows a summary of tsunami wave arrival times, in minutes, using different wave height thresholds from the Seattle Fault Zone (SFZ) 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.

Table 2. SFZ scenario, timing since start of earthquake minutes)

Location	TFirst Advis	TFirst Draw	TFirst Warn	TMax	TMin
City Dock	3	29	4	12	62
Head of the bay*	8	65	8	17	68
Mouth of Eagle Harbor	1	0**	1	2	0**
Ferry terminal	2	60	3	11	62

* Initializes as dry land in Mean Low Water simulation.
** Wave never drops below sea-level datum due to impact of subsidence.

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, the reason to implement them in emergency planning, and expands on their specific feasibility to be implemented for the City of Bainbridge.

Tsunami Response Actions

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

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.

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 City of Bainbridge

In the comprehensive evaluation of tsunami response actions for the City of Bainbridge, each potential action was evaluated based on its feasibility, classifying them as either 'Feasible,' 'Needs Review,' or 'Not Feasible.' This critical analysis considers the unique characteristics and vulnerabilities for the City of Bainbridge. The applicability of these response actions extends to scenarios involving both a Cascadia Subduction Zone (CSZ) and a Seattle Fault Zone (SFZ) 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 City of Bainbridge and Eagle Harbor. 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 City of Bainbridge and Eagle Harbor in the face of potential seismic events from both the Cascadia and Seattle Fault Zones.

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

The City of Bainbridge Island utilizes the Nixle mass notification software to distribute alerts up to 140 characters to fit into a single message. The Nixle software allows for individuals to be added to a specific group that can receive tsunami notifications. The Emergency Management Coordinator, Communications Coordinator, and other identified city personnel including Bainbridge Island Police Department Sergeants and Chiefs and Bainbridge Island Fire Department Battalion Chiefs have the ability to access Nixle and send out alerts for all types of emergencies. The Nixle system improves the redundancy of alerts sent out by the city as a primary tool in the alert dissemination toolkit. The City of Bainbridge Island's Emergency Management should collaborate closely with the community non-profit Bainbridge Prepares including the Flotilla leads, personnel from the privately-owned marinas, Map Your Neighborhood champions and liveaboards to establish effective notification processes to ensure that marina personnel and vessel owners can receive timely tsunami alerts.

While established lists are great for liveaboards and vessel owners who regularly visit or live in the area, Eagle Harbor remains a frequent destination for visitors and short-term liveaboards. Creating passive opportunities to educate short- or long-term harbor visitors can help inform vessel owners on recognizing tsunami hazards and actions to take before and during a tsunami to ensure the safety of themselves and the vessel, whether they are out in open water or their vessel is moored. Utilizing QR code stickers on tsunami signs in high-traffic areas is an easy way to enhance existing outreach efforts. Emergency Management should work with the community non-profit Bainbridge Prepares and the Flotilla leads to identify the information that is worth sharing on a boat-owner focused website.

Information on the website can also include additional methods to receive alerts, such as NOAA weather radios or VHF Radio Channel 16. The City of Bainbridge Island's Wildfire Response and Evacuation Plan published in 2022 outlines the full suite of methods through which alerts may be disseminated for a wildfire incident. The section outlines alerting methods that include Nixle, Kitsap County Rave messaging, Wireless Emergency Alerts (WEA), city website and social media (Facebook and X), Police and Fire PA systems, the Emergency Alert System (EAS), radio, print and television media, message boards on city property, and amateur radio systems run through the community non-profit Bainbridge Prepares. This section can be used as a template for the City of Bainbridge Island to develop a similar section for a tsunami response and evacuation plan. Specific details in the plan should include relevant tsunami-specific alerting details, such as EAS and WEA messages are automatically triggered from the federal level upon issuance of a tsunami warning.

The City of Bainbridge Island should confirm the use of the various alert methods for the different tsunami alert levels with National Weather Service's Weather Forecast Office in Seattle, Washington Emergency Management Division (WA EMD), Kitsap County Department of Emergency Management (KCDEM), and the Bainbridge Prepares partnership to ensure accuracy and alignment of existing and future roles and responsibilities in alert dissemination. If the City of Bainbridge Island creates a tsunami evacuation and response plan, the plan should be trained and exercised with critical response personnel and partners to ensure responsibilities are clear and understood.

Since becoming TsunamiReady® in early 2024, the City of Bainbridge Island has begun implementing tsunami-specific outreach to neighborhoods in the inundation zones. Additionally, two community-based workshops for tsunami preparedness were facilitated by the Emergency Management Coordinator. Continuing these efforts through regular education and outreach initiatives can increase public awareness and understanding of tsunami and risk-reduction actions community members can take to prepare themselves for tsunami incidents. By partnering with WA EMD and Kitsap County Department of 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 the City of Bainbridge Island, ensuring that community members, boat owners, and visitors are prepared to act swiftly and effectively during emergencies.

Through these combined efforts – working with the community non-profit Bainbridge Prepares, specifically the Flotilla group leads, to identify boat owners for the Nixle list, creating passive opportunities to expose short-term boaters and visitors to education and alert sign-ups, and using the Wildfire Response and Evacuation Plan as a foundation for a similar tsunami response and evacuation plan.

Evacuate Public and/or Vehicles from Waterfront Areas

Feasibility for the City of Bainbridge Island: Feasible

Evacuating people from waterfront areas ahead of a tsunami is a critical life safety measure designed to reduce casualties and minimize risks. In local earthquake scenarios, the emphasis should be on the evacuation of individuals rather than vehicles, as road conditions may be severely compromised by earthquake damage, and time is of the essence. Ensuring clear pedestrian evacuation routes and reducing reliance on vehicles in these situations is essential to effective life safety measures.

In the case of a local Cascadia Subduction Zone (CSZ) scenario, there is no expected inundation of the City Dock parking lot, making the evacuation of vehicles from this area unnecessary. For a local Seattle Fault Zone (SFZ) scenario, there is only time to Drop, Cover, and Hold On, immediately followed by heading to high ground on foot once the shaking stops. Efforts should instead focus on ensuring that people are safely out of the inundation zone before tsunami waves arrive. Attempting to move vehicles from this area could create unnecessary traffic congestion, complicating pedestrian evacuation and emergency response.

The post-earthquake environment will present extreme challenges for vehicular evacuation measures. Roads may be damaged or entirely unusable due to subsidence, liquefaction, or debris from collapsed buildings and fallen trees. Fires ignited by downed power lines or propane tanks, combined with reduced visibility from dust and smoke, could further hinder evacuation efforts. These conditions underline the need for adaptive, pedestrian-focused evacuation strategies and robust contingency planning for alternative routes and methods of evacuation. Infrastructure like the Winslow Way culvert, constructed in the 1940s, and the Agate Pass bridge, is particularly vulnerable, and its collapse could cut off critical routes.

Traffic management and aiding evacuation on foot is still a crucial consideration, specifically for the CSZ scenario with multiple hours of lead time. Law enforcement, public works, and community volunteers, such as those trained through Bainbridge Prepares or CERT, play a vital role in maintaining order and directing evacuees. However, resource limitations—such as only 4-5 officers on duty at a time—highlight the need for a collaborative approach and potential use of trained volunteers to manage evacuation zones.

Bainbridge Island's Wildfire Response and Evacuation Plan provides a valuable template for addressing these challenges. Real-time communication tools like Nixle and Wireless Emergency Alerts (WEA) could be adapted for tsunami-specific scenarios to inform residents of evacuation routes, assembly areas, and protective actions. Public education and regular evacuation drills, supported by Bainbridge Prepares, can further enhance readiness and reduce panic during an emergency.

Additionally, the integration of maritime systems into evacuation planning remains a complex challenge. The Washington State Ferry system on Bainbridge Island is a vital transportation link that must be factored into tsunami response plans. Close coordination between the City of Bainbridge Island, Washington Emergency Management Division and Washington State Ferries (WSF) is essential to ensure that their respective plans complement each other. Sharing terminal assessment procedures, evacuation strategies, and high-resolution modeling of ferry terminals can enhance safety and improve coordination.

Personal Floatation Devices/Vests for Port Staff

Feasibility for the City of Bainbridge Island: Feasible

The Lead Marine Officer always has a life jacket around, as he may need to rapidly respond utilizing the City of Bainbridge Island Police Department's boat, Marine 8. Extra life vests are available on the vessel. The Lead Marine Officer and Emergency Management Coordinator should work with the surrounding marinas and Map Your Neighborhood champions to ensure that marinas and boat owners have adequate floatation devices for themselves with a couple of backups on board.

Informing and Coordinating with Key First Responders During a Tsunami

Feasibility for the City of Bainbridge Island: Feasible

The Bainbridge Police Department expressed a desire to create a clear earthquake and tsunami communication plan with the Emergency Management Coordinator and other critical response partners to facilitate real-time information sharing among the Port Authority, US Coast Guard, Kitsap 911, and other emergency services. This plan should establish clear processes and protocols that can be exercised to ensure effectiveness. Opportunities to test and refine the plan include WA EMD's annual state-led tsunami exercise and the PACIFEX exercise organized by the National Tsunami Warning Center. These large-scale exercises provide an ideal platform to practice coordination, refine communication protocols, and identify potential gaps in preparedness.

Efforts to enhance communication infrastructure are already underway. The Emergency Management Coordinator noted the upgrades to the Emergency Operations Center (EOC), which now include Starlink internet and additional radio antennas to support emergency communication needs. The EOC will act as a central command post for coordination, activation of notification systems, and information dissemination to specialized groups and city staff. These upgrades provide a critical foundation for reliable communication during a tsunami, ensuring that first responders and other agencies remain informed and aligned in their efforts.

The involvement of the community non-profit Bainbridge Prepares further strengthens the feasibility of this measure. As a community organization, Bainbridge Prepares offers a trained volunteer network that can assist in response efforts. Bainbridge Prepares emphasized its readiness to support emergency operations through its Flotilla of 107 boats and its role in staffing the EOC. This collaboration can help supplement the efforts of professional first responders, especially in resource-constrained situations.

Coordination with other key agencies is also vital. For instance, Washington State Ferries (WSF) plays a critical role in regional transportation and tsunami response. Representatives from WSF discussed the importance of activating their EOC, conducting damage assessments, and coordinating vessel movements with regional emergency managers. Similarly, Washington State Department of Transportation's (WSDOT) involvement in managing State Route 305 and ensuring road functionality complements efforts to manage land-based evacuation.

Challenges remain, particularly in integrating Kitsap 911's capabilities into broader emergency management processes. Dispatch systems are likely to become overwhelmed during a large-scale disaster, necessitating additional coordination through Kitsap County Department of Emergency Management (KCDEM). The Emergency Management Coordinator noted the need for deeper collaboration with KCDEM and local police chiefs to streamline information-sharing processes and address gaps in understanding at the county level.

Training and resources are another area of focus. By the end of 2025, all Bainbridge Island police officers are expected to be certified in HAM radio operations, enhancing their ability to communicate when other systems fail. Mobile battery packs and potential mobile cell towers could provide additional power and communication capabilities during emergencies. These efforts reflect a proactive approach to addressing potential vulnerabilities.

This measure is highly feasible given the existing infrastructure, ongoing improvements, and strong interagency collaboration. Challenges such as dispatch system overloads and the need for more robust county-level coordination should be addressed through continued dialogue and planning. However, with proactive measures, such as regular drills, enhanced communication systems, and leveraging community resources like the non-profit Bainbridge Prepares, this measure offers a practical and effective path forward to improving tsunami response capabilities.

Activate Incident Command at Evacuation Sites

Feasibility for the City of Bainbridge Island: Feasible

The City of Bainbridge Island has recently relocated its Emergency Operations Center (EOC) from the City Hall building to a dedicated space at the Ted Spearman Justice Center, a facility shared between Bainbridge Island Police Department and the Court. This location, while not specifically chosen to avoid the tsunami inundation zone, benefits from its relative safety from tsunami impacts, offering a cross-beneficial decision for emergency operations and establishing centralized incident command. As this new EOC location is further outfitted with essential equipment—such as radios, laptops, satellite phones, and the recently acquired Starlink system for uninterrupted high-speed internet—securing these assets becomes paramount. Conducting a seismic security assessment to secure furniture, monitors, bookshelves, and strategic assets at the EOC would enhance its resilience during a significant earthquake, ensuring it remains operational for effective emergency response.

Activating an Incident Command-like structure at designated evacuation sites during a tsunami could be beneficial for establishing order and providing clear direction to evacuees. There are 15 identified assembly areas and 14 disaster hubs located throughout Bainbridge Island. During and immediately following a tsunami, evacuation sites are likely to be crowded, with people who may be injured, frightened, and seeking guidance. Setting up an Incident Command-like structure at these locations ensures a chain of command and span of control, with qualified personnel who understand the Incident Command System (ICS) and can fulfill leadership roles effectively. This organized structure helps reduce confusion, provides answers to evacuees, calms individuals under stress, and coordinates immediate response activities post-tsunami.

Having a structure like this at evacuation sites also enables direct communication with the EOC, facilitating efficient resource allocation and timely response adjustments based on real-time needs. By preparing these sites with structured command and control, Bainbridge Island enhances its capacity to manage the initial response phase, support evacuees, and mobilize resources for subsequent recovery actions effectively.

Activate Mutual Aid System as Necessary

Feasibility for the City of Bainbridge Island: Feasible

The City of Bainbridge Island has established formal mutual aid agreements with neighboring jurisdictions, including an interlocal agreement with Kitsap County Department of Emergency Management and nearby cities, and follows a structured process for requesting additional aid from the State government in times of emergency. There are also Memorandums of Understanding (MOUs) established with the parks district and local schools and churches for each disaster hub. These agreements provide a framework for collaboration and resource sharing, allowing Bainbridge Island to quickly mobilize external support when local resources are stretched thin. In large-scale emergencies, such as earthquakes or tsunamis, this network of assistance can be a vital lifeline, helping to bring in personnel, equipment, and specialized expertise from nearby areas less affected by the disaster. These agreements are part of a broader strategy to ensure the island can respond to and recover from disasters with a coordinated approach that leverages local, regional, and state resources.

Within this framework, the community non-profit Bainbridge Prepares stands out as an exemplary model of mutual aid and community-led preparedness. This nonprofit partnership focuses on building resilience across Bainbridge Island, emphasizing the mobilization and support of both the maritime and broader community in times of disaster. Combining the efforts of local government, emergency services, community groups, and individual volunteers, Bainbridge Prepares offers a replicable model of cooperation and resource allocation that other jurisdictions can follow. This organized, community-driven approach enables the rapid activation of local resources and volunteers, which can be complemented by external aid as needed.

A distinctive feature of the non-profit Bainbridge Prepares is its adaptability to tsunami and earthquake preparedness, with special attention to supporting both coastal and inland communities. In the event of such disasters, where local resources may be insufficient, Bainbridge Prepares can activate pre-arranged mutual aid agreements to bring in essential support from surrounding areas. This model demonstrates how a well-organized mutual aid system can bring additional personnel, equipment, and supplies into an area facing a disaster, allowing authorities to address the needs that exceed local capacity.

The mobilization of mutual aid resources during earthquakes and tsunamis presents unique challenges, especially considering the potential impact of high current speeds, wave amplitudes, and structural stability issues that such events introduce. The prestaging of these resources positioned on or near the water, like many resources a part of the Bainbridge Flotilla, may be compromised or rendered inaccessible if strong currents or waves damage docks, piers, or coastal storage facilities. Similarly, high-magnitude earthquakes can damage the structures housing essential equipment, making some resources unavailable at the critical moment they're needed. Storage locations play a crucial role in the viability of these resources; for example, supplies kept in earthquake-resistant buildings and elevated, secured locations away from potential tsunami inundation zones are more likely to remain intact and accessible.

To enhance the effectiveness of mutual aid in these scenarios, careful planning and consideration of where resources are stored, moored, and how they're transported are essential. Utilizing tsunami-resistant and seismically reinforced structures for critical supply storage can mitigate some risks, as can strategically positioning resources both inland and in multiple locations to reduce the likelihood of widespread damage. Properly securing and mooring maritime assets a part of the Flotilla would be essential as well with high projected current speeds and wave amplitudes in some areas. Additionally, relying on pre-arranged mutual aid agreements enables faster deployment from less affected nearby areas, bolstering local response efforts with supplies, personnel, and equipment that remain functional and accessible after the event. This proactive approach not only improves resource survivability but also strengthens the community's capacity to respond effectively to disasters, even when some local resources are compromised.

Conducting an official Tsunami and Earthquake Mutual Aid Workshop and review could be highly beneficial, utilizing site-specific modeling from this strategy alongside additional tsunami and seismic data. WA EMD and WGS could support these initiatives by effectively communicating hazards and risks to key decision-makers within the non-profit Bainbridge Prepares and the City of Bainbridge.

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

Feasibility for the City of Bainbridge Island: Feasible

This response measure faces several challenges, particularly related to the hazardous conditions likely to be present in tsunami-impacted areas. Stakeholders emphasized that waterways will be heavily obstructed by debris, making it unsafe for vessels to operate in the immediate aftermath of the disaster. Strong currents and contaminated waters will further exacerbate these risks, limiting the feasibility of deploying small boats for survey and response operations. Drone teams were identified as a vital resource for early reconnaissance, allowing responders to assess debris fields and identify safe pathways without putting personnel in danger. However, the success of this approach relies on having trained drone operators and access to necessary equipment.

Another critical component of this measure is the need for comprehensive training and resource development. While there are existing efforts to expand volunteer teams and provide formal training, significant gaps remain in maritime-specific damage assessment capabilities. Tools like Survey123 and other digital assessment platforms are being developed to streamline data collection and enhance response efficiency, but their effective implementation requires consistent training and practice. Moreover, resources such as fuel reserves, functional docks, and durable small boats are essential to support these operations. In the absence of such infrastructure, self-sufficiency from land-based resources will be heavily relied upon during the initial phases of response.

The Bainbridge Island Flotilla provides a compelling and practical model for integrating volunteer resources into emergency planning and response efforts. As a community-based program, the Flotilla leverages the skills and assets of recreational and commercial boat owners, along with their captains and crew members, to support critical operations such as transportation of supplies, emergency personnel, and patients, as well as environmental monitoring during emergencies. By mobilizing local maritime expertise, the Flotilla ensures that essential functions can continue even when traditional access points, such as bridges or ferry routes, are rendered unusable by a disaster.

The strength of the Bainbridge Island Flotilla lies in its adaptability and the strong community spirit it fosters. Volunteers train alongside emergency professionals, equipping them with the skills and knowledge needed to respond effectively and safely during crises. This training ensures that Flotilla members can operate confidently and efficiently in scenarios where swift action is needed to support the broader emergency response effort. Activation of the Flotilla is carefully managed, with protocols in place to ensure that resources are deployed at the right time and in the safest manner possible, particularly when dealing with hazardous post-disaster conditions.

The program also provides tangible incentives to encourage participation and maintain readiness. Fuel reimbursements for activated volunteers and those participating in citysponsored training sessions help reduce barriers to involvement. Comprehensive training programs further ensure that participants feel prepared and confident in their roles, strengthening the Flotilla's capacity to respond to emergencies. These incentives, combined with the program's collaborative approach, highlight the value of integrating local resources into disaster planning and response. Volunteers also actively participate in joint exercises with the City of Bainbridge Island Emergency Management and tsunami modeling maps and products from this Tsunami Maritime Strategy have been utilized to help inform the scenarios exercised. Given that over 80% of the Flotilla's vessels and assets are located in Eagle Harbor, more discussion of the viability and reliance on these assets in a post-SFZ and post-CSZ environment is warranted, especially considering the movement of vessels out of Eagle Harbor.

The Damage Assessment Annex for the City of Bainbridge Island, recently updated and strengthened by the Tsunami Maritime Strategy efforts, highlights the Flotilla's pivotal role in maritime damage assessment during disaster response. This group, including volunteers, Harbor Stewards, and the U.S. Coast Guard, works in coordination to evaluate damages to marine assets. Using standardized forms, the Flotilla systematically documents and reports findings to the Damage Assessment Branch in the EOC. Their contributions are vital to understanding the extent of damage to maritime infrastructure, which supports informed decision-making and resource allocation during recovery. Through continued coordination with the City of Bainbridge Island's Emergency Management Coordinator and GIS teams, and attending future unreinforced masonry (URM) workshops, these processes will continue to be built out, exercised, and refined.

The overall Damage Assessment Annex provides a comprehensive framework for responding to disasters by prioritizing timely and accurate evaluation of damages. It outlines responsibilities, procedures, and tools for assessing critical infrastructure, establishing a clear path from initial surveys to detailed evaluations. To ensure readiness and efficiency, the annex recommends regular training and exercises, including specific preparation for Flotilla members, to strengthen their ability to perform maritime assessments effectively.

The Bainbridge Island Flotilla stands as a testament to the power of community-driven preparedness and action. By aligning local expertise, volunteer enthusiasm, and professional emergency management, the Flotilla has created a framework that not only enhances the island's resilience but also offers a scalable model for other maritime communities. This program exemplifies how leveraging local resources and fostering community engagement can strengthen disaster response efforts, providing inspiration for other regions seeking to build their preparedness and support networks.

The United States Coast Guard (USCG) serves as a vital partner in the implementation of the measure to pre-identify personnel for rescue, survey, and salvage efforts following a tsunami. With its statutory authority over the safety, security, and navigability of the nation's waterways, the USCG provides essential leadership and coordination in maritime disaster response. Their mission aligns closely with the objectives of this measure, ensuring that personnel tasked with rescue, survey, and salvage operations are effectively supported and integrated into broader response efforts.

The USCG's post-tsunami responsibilities, including maritime search and rescue (SAR), navigability assessments, and the identification of hazardous materials spills, underscore the importance of having a well-prepared team of local responders who can complement federal efforts. Pre-identified personnel, such as trained volunteers, port staff, and specialized maritime operators, can work alongside the Coast Guard to enhance response capacity, particularly in conducting localized assessments of port facilities, navigation channels, and damaged infrastructure. The presence of these trained individuals ensures that critical information can be gathered quickly, enabling the USCG to make informed decisions about the reopening of waterways and the restoration of maritime transportation systems.

Additionally, the USCG's ability to broadcast tsunami warnings and protective actions to mariners highlights the importance of seamless communication between federal authorities and local personnel. Pre-identified teams can act as liaisons, relaying information to on-the-ground responders and helping to prioritize rescue and salvage operations based on real-time conditions. These teams also play a crucial role in supporting the USCG's environmental response efforts by assisting in the identification and mitigation of hazards, such as debris fields or contamination, that could impede recovery operations.

By pre-identifying and training personnel for these roles, communities can strengthen their collaboration with the USCG, ensuring a more coordinated and effective response. This partnership not only enhances local readiness but also supports the Coast Guard's broader mission of protecting lives and restoring the safety and functionality of Washington's waterways in the aftermath of a tsunami. Integrating pre-identified teams with USCG operations exemplifies the importance of a unified approach to maritime disaster response, leveraging local expertise to complement federal capabilities.

Ultimately, the feasibility of pre-identifying personnel for rescue, survey, and salvage efforts depends on addressing key challenges and leveraging proven strategies. By investing in training programs, developing resources like drones and durable boats, and establishing clear activation protocols, this measure can significantly enhance post-tsunami response capabilities. The integration of community-based initiatives, such as volunteer Flotillas, further strengthens the measure by fostering a sense of shared responsibility and utilizing local expertise. While challenges remain, this approach offers a practical and effective path forward for ensuring a swift and coordinated response to future tsunami events.

Secure Moorings of City-Owned Vessels

Feasibility for the City of Bainbridge Island: Feasible

The only city-owned vessel on the dock is Marine 8. The Lead Marine Officer maintains responsibility for the vessel and should maintain proper measures to secure the vessel each time it is docked.

Given the vast amount of privately- or commercially-owned maritime infrastructure in Eagle Harbor, other opportunities to educate the public should be utilized. It is not feasible for the city staff to secure all moorings, so incorporating methods and emphasizing the importance of properly securing vessels anytime it is moored is essential for protecting property. This helps reduce damage to vessels and minimize the potential for boats to break loose from the docks.

The Emergency Management Coordinator, along with the Bainbridge Prepares non-profit, specifically the Flotilla group, and Map Your Neighborhood groups should work together to incorporate this information as part of future educational opportunities, which have proven to be successful for other recent tsunami-related information. Additionally, the city should emphasize the importance of proper mooring in public education materials and other communications to ensure marina users comprehend the benefits of securing their vessels during tsunami events. WA EMD will continue working with the city to provide tsunami response recommendations for boaters including the distribution of the Tsunami Boater's Guide to their users.

Shut Down Port Infrastructure Before Tsunami Arrives

Feasibility for the City of Bainbridge Island: Needs Review

There are no currently outlined Standard Operating Procedures (SOPs) to shut down the Harbor's infrastructure. Since most of the maritime infrastructure is privately-owned, the city would have to draft a Memorandum of Understanding (MOU) with privately-owned entities to assist given the limited capacity and access of local first responders for the private marinas. Other opportunities for coordination for shutting down maritime infrastructure exist but would require additional MOUs or agreements are established. This includes with staff at Winslow Wharf Marina (staffed from 9-5), Queen City Yacht Club, Tyee Yacht Club, Eagle Harbor Yacht Club, Harbor Marina, Williamson Landing Marina, Bainbridge Island Marina and Yacht Club, Map Your Neighborhood groups within the Eagle Harbor area, and other commercial organizations who own maritime infrastructure. Other challenges should be addressed, such as ensuring that those responsible for shutting down infrastructure have a backup for out-of-town trips or handling overnight responsibilities outside of primary business hours for commercial organizations, as seasonal and private marina staffing may vary throughout the year. The Emergency Management Coordinator should develop printed or electronic material outlining recommended response actions for all non-city-owned marinas as this could be an effective approach for educating community members.

As for the City Dock itself, part of the upgrades that were incorporated five years ago in the infrastructure upgrades included smart pedestals that activate upon detection of a stray current or faulty wiring. These pedestals will automatically shut down the flow of electricity, reducing the risk of electrocution for liveaboards and vessel owners. This gives the Lead Marine Officer or other responders one less action to cover in tsunami response, allowing them to prioritize other critical tasks. As other communities work to upgrade or replace old maritime infrastructure, considering a similar aspect in their design is crucial to tsunami response efforts.

Additionally, coordinating with Puget Sound Energy (PSE) to learn about their infrastructure and tsunami response plans will be critical to understanding feasible protective actions given potential earthquake impacts and limited response times for tsunamis. The Emergency Management Coordinator should work with members of PSE and the Bainbridge Island Police and Fire Departments to learn more about PSE's role in shutting down infrastructure.

The Wastewater Treatment Plant (WWTP) is exploring the possibility of incorporating Earthquake Early Warning (EEW) automatic shutoffs into their systems for automatic shutoff valves upon notification of an earthquake. The Emergency Management Coordinator should work closely with the WWTP on updating procedures and incorporating the procedures to share lessons with Utilities, Public Works, or other agencies who may have an opportunity to utilize the EEW system.

The WSF Ferry maintenance yard has on-site staff almost 24/7 and have developed initial procedures for notification and steps to take. It is recommended that WSF Ferries brief the Emergency Management Coordinator on their plans for shutting down their infrastructure for both the public terminal and the maintenance yard.

Move Vessels Out of the Port

Feasibility for the City of Bainbridge Island: Needs Review

Given the uncertainty in the source of a major earthquake that causes severe shaking for the City of Bainbridge Island, all education efforts should emphasize heading inland to high ground when the shaking stops. However, the city does not have the authority to instruct boat owners to take specific actions regarding their vessels during a tsunami. While first responders are evacuating coastal areas, many boat owners may try to reach their vessels to take them out to deeper water in the Puget Sound instead of leaving them docked.

Additional conversations are needed to determine whether allowing vessel owners to ride out the tsunami is feasible in the Puget Sound, specifically in and around Elliott Bay, between Bainbridge Island and the City of Seattle. WA EMD can help facilitate conversations between the USCG and City of Bainbridge Island to benefit maritime partners across the state and improve the coordination and understanding of roles and responsibilities in tsunami response for better decision-making and planning efforts. The City of Bainbridge Island should coordinate closely with first responders, the community non-profit Bainbridge Prepares' Flotilla group, private or commercial marina owners, and Map Your Neighborhood Captains for future documentation, drafting and review of plans for vessel-related response actions.

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

Feasibility for the City of Bainbridge Island: Needs Review

Key to this measure's feasibility is the ability to implement immediate and decisive traffic control in the face of a tsunami warning. While it is not feasible to restrict reentry across the island, smaller portions of the island, like the Bainbridge City dock, would be feasible for closure. Closing gates to marina entrances and blocking roadways with barriers such as marina vehicles are straightforward actions that can prevent vehicular and pedestrian access to hazardous areas. However, managing the evacuation of those already in the zone requires clear signage, temporary barriers, and personnel equipped to direct traffic efficiently. Personnel involved must have high-visibility clothing, flashlights, and proper training to safely and effectively guide evacuees away from danger.

The wildfire response and evacuation plan for Bainbridge Island provides a valuable template for restricting reentry into tsunami inundation areas. This plan details the use of traffic control points, managed by law enforcement and supplemented by Public Works staff and CERT volunteers, to ensure orderly movement out of affected zones. These principles can be adapted to the tsunami scenario, with additional emphasis on high-visibility evacuation aids such as signs and barriers to redirect traffic swiftly. However, the post-earthquake environment may complicate these efforts. Earthquake-induced road damage, such as buckling, subsidence, and landslides, could render key evacuation routes impassable, limiting the feasibility of the measure. Fires, debris, and poor visibility due to dust and smoke further highlight the need for adaptable strategies.

Effective public communication and outreach are essential components of this measure. The wildfire plan's use of mass notification systems such as Nixle and Wireless Emergency Alerts (WEA) can be directly applied to tsunami response efforts. Alerts must clearly convey the urgency of the situation, evacuation routes, and the restricted access to port areas. Educational campaigns and drills conducted ahead of time can familiarize residents with evacuation procedures and build trust in the response system, reducing panic during an actual event.

The feasibility of this measure also depends on resource availability, especially with who is on island during an earthquake and tsunami, and prioritization in a post-earthquake context. Given the widespread damage expected from a local earthquake, including to critical infrastructure and emergency services, resources may be diverted to higher-priority needs such as search and rescue or medical aid. This limitation underscores the importance of pre-planning and coordination with community organizations like the non-profit Bainbridge Prepares, which can supplement efforts by providing credentialed and trained volunteers to manage traffic control and support evacuation activities.

Despite the challenges, this response measure may be achievable with robust pre-incident planning, community engagement, and adaptive strategies. Integrating elements of the wildfire response framework, such as traffic control points and real-time public communication, can enhance its effectiveness. However, further discussions and contingency planning are needed to address the unique challenges posed by a post-earthquake environment and who is on island. These efforts will ensure that restricting traffic and aiding evacuation remain viable and effective components of the broader tsunami response strategy.

Pre-Stage Emergency Equipment Outside Affected Area

Feasibility for the City of Bainbridge Island: Needs Review

The City of Bainbridge Island's Emergency Operations Center (EOC) recently moved from the City Hall building to its own space at the Ted Spearman Justice Center, a city facility shared with the Bainbridge Island Police Department and the Court. Work is still ongoing but the EOC is expected to be operational in early 2025. The location of the new EOC is safe from the impacts of a tsunami. The Emergency Management Coordinator should ensure that the EOC is fully equipped with radios, laptops, satellite phones, TVs, and all the necessary equipment once it is complete. Starlink systems are being installed at the EOC to ensure the availability of high-speed internet should existing infrastructure be damaged from the impacts of a large earthquake and tsunami.

The Bainbridge Island Police Department's response boat, Marine 8, is currently located on a dock that is not city-owned. This vessel is crucial for water-level response around the entire island, so ensuring the safety and protection of the vessel can ensure that Police personnel can take part in response activities once the tsunami threat is over, such as coastal damage assessments. The City of Bainbridge Island's Emergency Management Coordinator should work within the Bainbridge Prepares partnership to identify other assets that can be utilized in tsunami response.

Working with the Flotilla group of the non-profit Bainbridge Prepares will be important to identify how the Flotilla group can respond once the tsunami threat is over. Inventorying information on the overall number and capabilities of vessels available to respond to a tsunami will be crucial to future planning efforts. This will be especially important as some Flotilla members live in surrounding communities such as Poulsbo and Fletcher. This information can be stored and updated as a spreadsheet and visualized in a map to provide a better idea of which boats are currently docked and which are currently on land. Given possible damage from the earthquake to the Agate Pass Bridge, the only way on and off the island by car, and the impacts of tsunamis to maritime infrastructure around the entire island, working to educate Flotilla members on how and when to check the operability of their boats post-tsunami is a key step in preparing the Flotilla for effective response. Boats that are already out of the water when the earthquake hits may be ideal candidates in response if they are not impacted by the earthquake or tsunami.

The Flotilla's role in navigating around Bainbridge Island could prove to be a crucial step in tsunami response. Many of the folks required to respond to emergencies live off-island and would need transportation to fulfill their response roles. Given the unknown status of the Agate Pass Bridge post-earthquake and tsunami, the Flotilla can fill the transportation gap and help move people and supplies to the surrounding islands. The primary challenge from developing and exercising Flotilla-related plans is due to the uncertainty of how the U.S. Coast Guard will manage the waterways of Washington, as they maintain primary responsibility for the safety and navigability of coastal waters in any emergency.

Other heavy equipment could also be staged in pre-identified areas near expected impact zones or other areas that may be critical to response efforts, such as the area surrounding Eagle Harbor Drive NE where it intersects at the head of the bay. Identifying locations that are accessible and safe from both the impacts of tsunami hazards and for those who need to access them is a critical part of the response plan. Once sites have been identified, conducting drills or exercises to pre-stage equipment at those sites will ensure that all personnel are familiar with the process and can execute it quickly when necessary.

Remove or Secure Hazardous Materials Used or Owned by Port

Feasibility for the City of Bainbridge Island: Needs Review

The Emergency Management Coordinator should work with private marina owners, the Flotilla group within the community non-profit Bainbridge Prepares, Washington State Ferries and the Lead Marine Officer to identify the locations of hazardous materials within Eagle Harbor. Outreach should be conducted with boat owners and liveaboards on the importance of securing hazardous materials in case of a tsunami. If needed, the Emergency Management Coordinator can support the drafting of Standard Operating Procedures (SOPs) to reduce the risk of a hazardous materials spill.

Additionally, the Emergency Management Coordinator should work with the Environmental Protection Agency to better understand how the hazardous materials at the local Eagle Harbor/Wyckoff Superfund site may impact maritime response and operations after a tsunami.

Reposition Ships Within the Port

Feasibility for the City of Bainbridge Island: Not Feasible

Since Eagle Harbor is full of existing maritime infrastructure, with the vast majority of it outside of city control, repositioning ships with Eagle Harbor is not a recommended measure. Given that the City of Bainbridge Island will experience severe levels of shaking in both CSZ and SFZ earthquakes, it may be difficult in the moment to determine how much response time is available for the community. Therefore, it is recommended that life safety is prioritized above all else and the focus lie in evacuation away from the marina and proper moorage of vessels.

Additionally, the City of Bainbridge Island does not have the authority to handle privately owned vessels or require them to move during a tsunami. The Emergency Management Coordinator and first responders 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 Emergency Management Coordinator should work with the community non-profit Bainbridge Prepares (including the Flotilla group) to 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 City of Bainbridge Island: Not Feasible

Eagle Harbor has a single public boat launch located at the City Dock 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 city personnel to higher ground rather than removing vessels from the water. Given that the City of Bainbridge Island will experience severe levels of shaking in both CSZ and SFZ earthquakes, it may be difficult in the moment to determine how much response time is available for the community. Therefore, it is recommended that life safety is prioritized above all else and the focus lie in evacuation away from the marina, not in the removal of small vessels from the water before the first waves arrive.

In line with other recommended response measures outlined in this strategy, the city 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 City of Bainbridge Island: Not Feasible

It is important to note that removing buoyant assets from the water is not advisable since the City of Bainbridge Island will experience severe levels of shaking in both CSZ and SFZ earthquakes, making it potentially difficult in the moment to determine how much response time is available for the community. Instead, the primary focus should be on directing both the public and city personnel to higher ground during tsunami events. This approach prioritizes life safety over the removal of city-owned buoyant assets from the water.

Aligned with other recommended response measures in this strategy, the city 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 City of Bainbridge Island: Not feasible

The US Coast Guard can restrict the entrance of recreational traffic into or out of the Harbor, which they do for hazardous bar conditions. More coordination between the City of Bainbridge Island, Washington State Ferries, WA EMD and the Coast Guard is recommended to clarify roles, responsibilities, and response actions.

The city 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 city should work with WA EMD and the non-profit Bainbridge Prepares Flotilla 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 city 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. The QR codes linking to a tsunami-specific page is a great educational opportunity to provide this sort of information.

Section 5: 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 Eagle Harbor, 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

Figure 38: Tsunami kiosk featuring evacuation route in Oceanside, CA.

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 use 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 built informational kiosks to inform the public of tsunami dangers, such as the evacuation kiosk shown in figure 38.

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

Figure 39: 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 39). 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 40: 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 40). 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

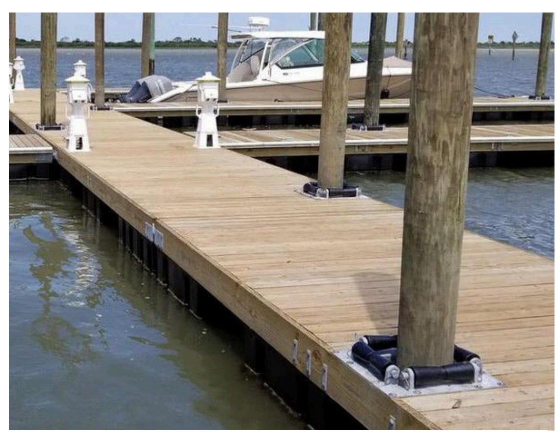


Figure 41: Floating docks with square pile guides for each piling (americanmuscledocks.com).

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 41).

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 42). These styles, while common,

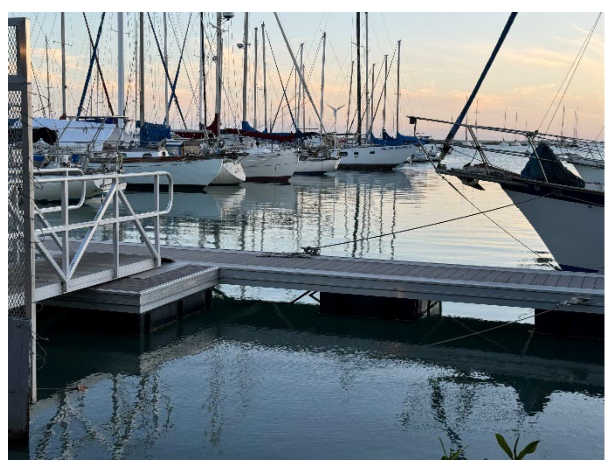


Figure 42: Docks built on floating blocks in Honolulu, Hawaii (WA EMD)

will not prove as buoyant as docks with a floatation section that spans the entire underside of the dock area.

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

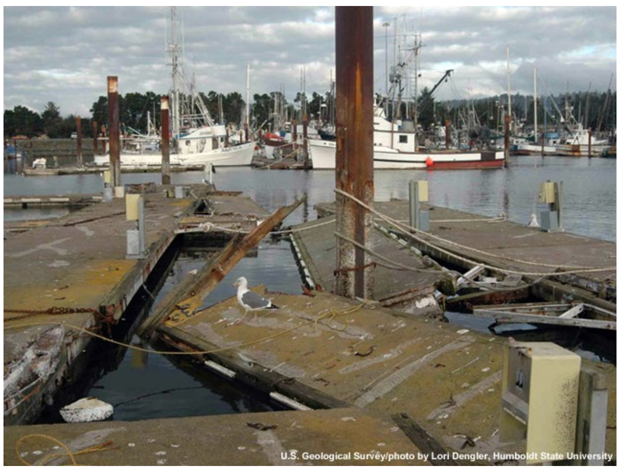


Figure 43: Broken docks in Crescent City, CA from the 2006 Kuril earthquake (USGS 2006).

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 43, 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

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 44. 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.

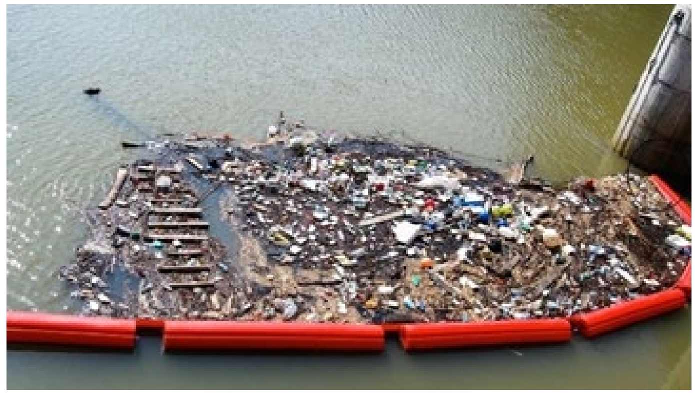


Figure 44: Debris deflection boom (Worthington Waterway Barriers).

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

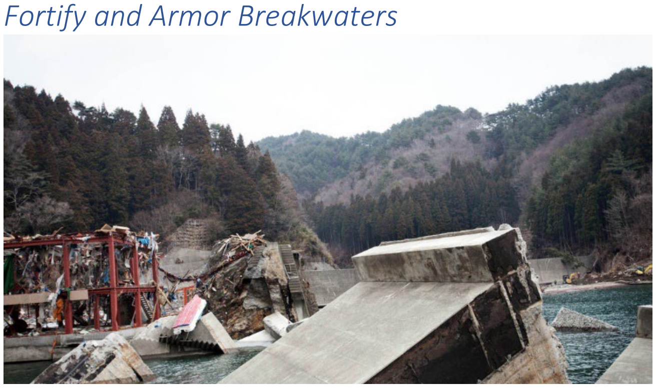


Figure 45: The Kamaishi breakwater, which failed during the 2011 Japanese tsunami (NY Times).

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 45, 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.

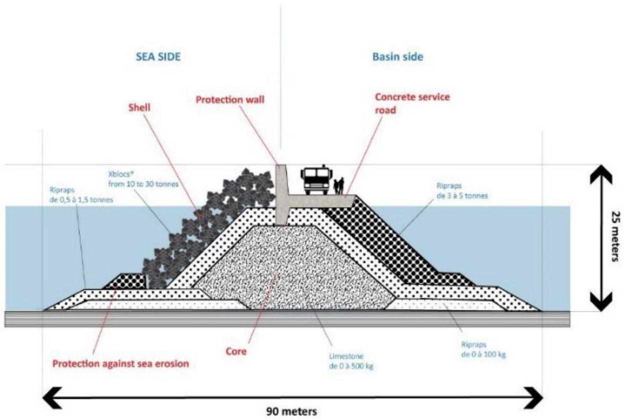


Figure 46: Diagram of fortified breakwater.

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 46. 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 47.

Figure 47: 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 48). 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 48: 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 49: Floodgates in Fudai, Japan stand tall after the 2011 tsunami. (NBC News)

The construction of floodgates has proven successful in several locations to lessen or eliminate inundation from tsunami waves. While the largest and most powerful tsunamis can overtop or otherwise breech floodgates, they have proven extremely effective during smaller tsunamis, and even during large tsunamis in locations with less inundation. Japan has constructed several massive floodgates that proved effective against tsunami waves, like the floodgate pictured in Figure 49.

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 Eagle Harbor

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

Actions deemed 'Complete' are tsunami mitigation actions that have already been completed in Eagle Harbor to reduce the impacts of a tsunami. For Eagle Harbor, they completed a set of infrastructure upgrades on the city-owned dock in 2019, creating a valuable template for other marinas in the area and communities across the state of Washington to utilize in their own mitigation efforts. 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 Eagle Harbor. 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 Eagle Harbor in the face of potential seismic events from both the Cascadia Subduction Zone and Seattle Fault Zone.

Mitigation Actions	Feasibility for Eagle Harbor
Improve Floatation Portions of Docks	**Complete**
Increase Size and Stability of Dock Piles/Increase Height of Piles to Prevent Overtopping	**Complete**
Increase Flexibility of Interconnected Docks	**Complete**
Strengthen Cleats and Single Point Moorings	**Complete**
Movement of Docks Along Pilings	**Complete**
Install Tsunami Signs	**Feasible**
Debris Deflection Booms to Protect Docks	**Feasible**
Reduce Exposure of Petroleum/Chemical Facilities and Storage	**Needs Review**
Acquire Equipment/Assets to Assist in Response Activities	**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 Harbor	**Not Feasible**
Fortify and Armor Breakwaters	**Not Feasible**
Deepen or Dredge Channels Near High Hazard Zones	**Not Feasible**

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

Feasibility of Mitigation Action: Complete

As part of the 2019 city dock infrastructure upgrades, flexibility and motion between floats was an essential part of the design process. A 12-inch gap between the boarding and mooring floats covered with a transition plate allows the dock to accommodate the full tidal range of motion (City of Bainbridge Island Waterfront Dock Renovation Proposed Plan, 2017). Dock floats themselves were built with hinges that allow for flexible movements between the individual floats (see figure 50) while maintaining the utilities and electrical supply that runs within the docks. Additionally, the dock construction consists of aluminum framing and walers to support connections, allowing for some additional bending in stress-inducing situations compared to other types of metal.

Figure 50: Example connection between boarding floats and floating tub example at the city-owned dock. (WA EMD)

The design used to connect the floats across all parts of the dock will better withstand the drastic short-term water-level changes expected during a tsunami and may reduce the damage to the dock infrastructure compared to outdated, wooden dock infrastructure. The design used to connect the individual floats is a great example of how maritime infrastructure can be designed to mitigate the impacts of a tsunami and can be used as a template to help other communities in their dock infrastructure replacement or upgrade process.

The dock portions are also designed with float tubs. These tubs are typically stuffed with polyethylene foam in a durable plastic coating, which creates a very lightweight and durable floatation solution for maritime infrastructure. They are resistant to damage from UV light, the impacts of tidal action or other marine wildlife, and the harsh conditions of salt water that may be mixed with contaminants such as oil or gas. Floats of this type are compatible with a wide range of materials, including wood, steel, or aluminum and are built to withstand any punctures or break in the casing of the tub itself. They are lightweight and can support weights twenty or thirty times the weight of a single float tub.

The float tubs are an excellent example of floatation for maritime infrastructure that can help mitigate the impacts of a tsunami compared to fixed docks. They allow for more freedom of movement, are durable, and require less maintenance. This means that they are able to adapt to changing water-level conditions more effectively and may perform better to increased current speeds and debris loads from a tsunami.

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

Feasibility of Mitigation Action: Complete

In the infrastructure updates for the city dock that were completed in 2019, timber pilings were replaced with galvanized steel pilings. The new pilings were installed to a height of 19 feet above Mean Lower Low Water and 7.5 feet over Mean Higher High Water levels (City of Bainbridge Island Waterfront Dock Renovation Proposed Plan, 2017) which are adjacent to the levels of which inundation from storm tides typically occur. The 7.5 feet above Mean Higher High Water levels are sufficient to account for the expected 5 – 6 foot simulated maximum wave height at the city dock for a Cascadia Subduction Zone earthquake and tsunami as part of this study. Additionally, pilings offshore on the mooring floats were built twice as thick as the pilings on the boarding floats closer to land (Figure 51). Efforts were taken to ensure that pilings were secured in the ground approximately 20 feet from the surface support to stabilize the infrastructure, leading to pilings between 30 – 80 feet long in total.

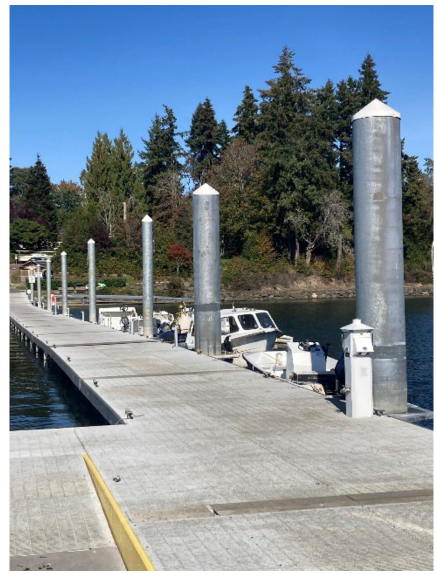


Figure 51: Pilings on the city-owned dock. Pilings further towards shore are half the diameter as the mooring pilings in the center and right of the photo (WA EMD)

While the pilings were designed with expected sea-level rise and climate impacts in mind, these efforts also helped mitigate expected water-level changes associated with a CSZ earthquake and tsunami. Although the piling heights would likely not be enough to withstand water-level changes from a SFZ earthquake-generated tsunami, a large earthquake and tsunami is more likely to occur in the near future from the CSZ and will more frequently impact the coastline of Bainbridge Island. This work can lead the way and act as a template for other communities as they undergo their own infrastructure upgrades or rebuilds utilizing hazard-specific planning and implementation into their own projects.

Strengthen Cleats and Single Point Moorings

Feasibility of Mitigation Action: Complete

The infrastructure at the city-owned dock in Eagle Harbor was replaced in 2019. The south end of the dock features a 5-foot-long aluminum bullrail designed for large vessels up to 130 feet long

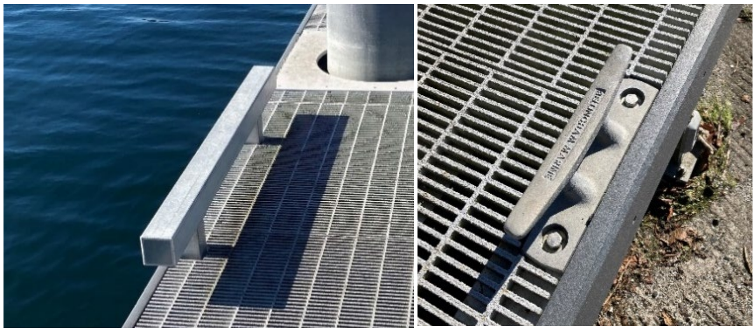


Figure 52. An example bull rail (left) and cleat (right) at the City Dock within Eagle Harbor (WA EMD).

(see figure 52). Throughout the rest of the dock, smaller 15-inch-long aluminum cleats were installed on the rest of the dock where smaller vessels would be able to navigate. These recently upgraded cleats are a great example of effective tsunami mitigation and will contribute to reducing the overall impacts of a tsunami by ensuring secure connections for vessels to the infrastructure. They provide two great examples of cleats that can accommodate a wide range of vessels and can provide a great reference for communities who want to upgrade or replace their cleats for their maritime infrastructure.

Improve Movement of Dock Along Dock/Pilings

Feasibility of Mitigation Action: Complete

One of the primary sources of damage to maritime infrastructure in a tsunami is due to a limited or restricted ability of the dock to move along a piling during rapid water-level changes. Docks may often jam against pilings, which can lead to the dock being overtopped by the water's surface. Once the dock is below the water's surface, the force of the tsunami and debris can heavily damage existing infrastructure, or may break the dock's connection to the piling, creating additional debris for the tsunami to carry in its path. Additionally, docks may be designed with hoops that do not grant freedom of movement along the piling, increasing the likelihood of binding and drastically increasing the likelihood of damage in a tsunami.

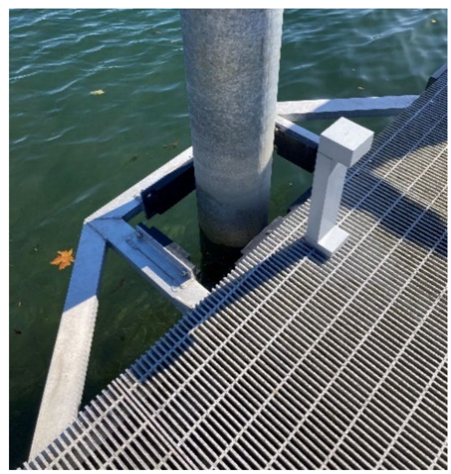


Figure 53: Floating docks with square pile guides for each piling (americanmuscledocks.com).

The recent infrastructure improvements to facilitate the movement of the city dock piling include a 1.5-foot by 2.5-foot clearance with rub strips installed to protect the dock from damage from the piling (Figure 53). Pile hoops are squarely built with aluminum and attached to the dock with steel bolts, allowing for freedom of movement of the piling while maintaining a strong connection to the dock infrastructure itself. This design can act as a template for other maritime communities who wish to build new infrastructure or replace their current infrastructure. The specific features they used (ample space for the piling to move, rub strips to reduce wear and tear, construction materials) are ideal components to reduce damage from the rapid water-level changes a tsunami creates.

Install Tsunami Signage

Feasibility of Mitigation Action: Feasible

Figure 54: An informational kiosk near the entrance of the city-owned dock provides a great opportunity to house tsunami information. (WA EMD)

This is an action that can be easily implemented in Eagle Harbor and would address a significant need for improving signage, especially near the city-owned dock. Continuous education for vessel owners is a priority for the City of Bainbridge Island and additional signage can help bolster those efforts moving forward. Placing signs in high-traffic areas would ensure that visitors, liveaboards, and vessel owners that utilize docks in Eagle Harbor would have the chance to learn about tsunami hazards and easy steps to prepare for them. The small informational kiosk at the entrance of the city-owned dock (figure 54) is one potential location that could easily house tsunami-related information. The kiosk itself is already city-owned property and has ample space to include informational signage, such as evacuation route or tsunami alert information. For tsunami evacuation wayfinding, the Emergency Management Coordinator has identified that one additional tsunami assembly area sign is required.

Over the past several years, the Emergency Management Coordinator has worked with Washington Emergency Management Division (WA EMD) on wayfinding and potential sign locations, the City of Bainbridge Island Public Works Department for sign creation and installation on city-owned roadways, and the City of Bainbridge Island Parks Department for installation on Parks property. Once the new evacuation routes were identified and signs were installed, the Emergency Management Coordinator helped coordinate an effective public outreach campaign to explain Bainbridge Island's tsunami risk and why the signage was important. This included three open community forums, a City Manager's report to a few thousand resident subscribers, an article in City Connects (a community-wide newsletter that is mailed to all city addresses), and posts on the City of Bainbridge Island website, social media, a press release in conjunction with a TsunamiReady® designation through National Weather Service with WA EMD present, Map Your Neighborhood Captains meetings, and a local podcast as well. Utilizing this wide range of outlets ensured that community members were aware of the signage and were able to learn about how tsunamis could impact Bainbridge Island as well. With the newly established set of signs, the Emergency Management Coordinator should work with Public Works, Parks, and the community non-profit Bainbridge Prepares for opportunities to further education, particularly for visiting or maritime populations, by adding QR codes on existing tsunami signage.

The City of Bainbridge Island can work with WA EMD to review existing evacuation routes and identify optimal locations for new signage. This initiative could include wayfinding signage (e.g. tsunami evacuation route signs with arrows, evacuation route information) and information signage to educate port users about tsunami risks, alerts, and evacuation procedures.

Historically, EMD has had available funding to help cover purchasing and installation costs for tsunami signage, although recent budget cuts have halted that option for now.

Additionally, the Bainbridge Island ferry terminal has a suite of informational material available for their customers and is an opportunity to share Bainbridge Island related tsunami information. The City of Bainbridge Island should work with Washington State Ferries to see how tsunami information can be posted within the ferry terminal.

Debris Deflection Booms to Protect Docks

Feasibility of Mitigation Action: Feasible

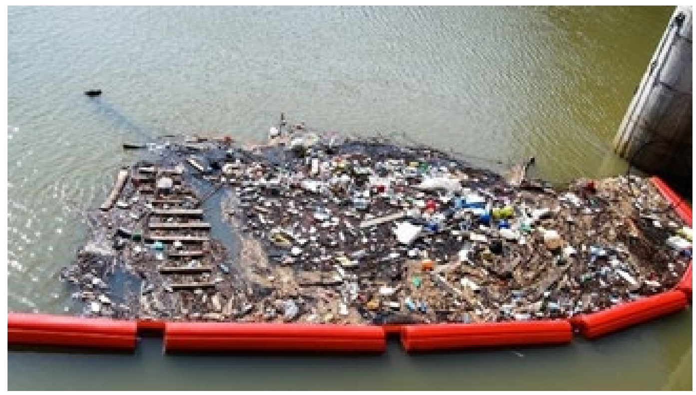


Figure 55: Debris deflection boom (Worthington Waterway Barriers)

The City of Bainbridge Island has a few oil booms in their supply but would benefit from gathering debris booms (figure 55). While these booms would be ineffective in a SFZ earthquake and tsunami, booms could be effectively deployed in response to a CSZ tsunami threat to block debris from impacting infrastructure or vessels in the area. Given the significant dock infrastructure in Eagle Harbor, deploying booms on either the north or south side of the harbor can mitigate a significant amount of damage, or even be used to channel debris to a specific area to ensure speedy clean-up and fewer disruptions to maritime operations for the community. This would be a lower cost mitigation action that is feasible for the City of Bainbridge Island to undertake.

Reduce Exposure of Petroleum/Chemical Facilities and Storage

Feasibility of Mitigation Action: Needs Review

Currently, the Wastewater Treatment Plant located in Winslow lies in the inundation zone for the Seattle Fault Zone earthquake and tsunami scenario. While there is no formal plan right now for what staff should do, three or four staff members are always on the grounds, with additional staff available from 6:00 AM to about 4:30 PM during normal operating hours. While the most effective mitigation effort for the plant may be to relocate it out of the inundation zone to another location, the overall planning, logistics, and funding for a project of this magnitude creates a significant barrier.

Additionally, city-owned water pumps and other wastewater infrastructure have historically been impacted from other similar flooding events, including king tides and extreme rain events. The Emergency Management Coordinator has identified six pump stations that are either in the inundation zone, or very close to it. Other facilities around the island, including off Eagle Harbor Dr NE at the head of the bay, should be identified and mapped for a better understanding of potential impacts on this vital infrastructure. The Wastewater Treatment Plan staff should work with the Emergency Management Coordinator from the City of Bainbridge Island to develop procedures to shut down facilities after an earthquake and discuss other potential mitigation options to reduce impacts to wastewater facilities and infrastructure across Bainbridge Island.

Outside of wastewater infrastructure, there are oil depots (such as Manchester in Port Orchard) in the surrounding area. Shipping channels surround the coast, particularly on the east side of Bainbridge Island, which increases the risk of chemical or petroleum spills. This is of particular concern in a local SFZ earthquake and tsunami, in which waterborne vessels may only have a couple minutes to react.

Lastly, the Eagle Harbor/Wyckoff Superfund site poses a major threat for cascading environmental impacts from a tsunami. Although the land is owned by the city, ongoing cleanup efforts are the responsibility of the Environmental Protection Agency. The site is still decades away from being cleaned up fully. While a 70-foot barrier of sand was layered on top of the existing creosote and contaminants, the energy carried with a tsunami would almost surely disturb the sediment and create a secondary environmental disaster that would significantly hamper the City of Bainbridge Island's and the Flotilla Group of the non-profit Bainbridge Prepares' ability to effectively respond to the impacts of a tsunami.

Acquire Equipment/Assets to Assist in Response Activities

Feasibility of Mitigation Action: Needs Review

Currently, the Bainbridge Island Police Department owns a single vessel (Marine 8) that is utilized for emergency situations. However, the vessel is currently located on a private dock owned by the Queen City Yacht Club, which although secure and recently upgraded, is limited from using public funds on upgrades to mitigate future tsunami impacts in an area where inundation and current speeds may cause damage to the dock infrastructure. The Lead Marine Officer for the Bainbridge Island Police Department is working to identify alternate locations to build an earthquake- and tsunami-resistant small dock that could be utilized by multiple agencies and enhance the local response to a wide range of emergencies.

Features of this dock should include a tsunami- and earthquake-resistant design that utilizes strong building materials and design aspects, similar to the city-owned dock infrastructure that was upgraded in 2019, which included tall metal pilings that allow for freedom of movement for the rest of the dock, effective dock floatation, securely-fastened metal cleats, and flexible connections between dock pieces. This dock would ideally include 5 slips – one for Bainbridge Island Fire Boat, one for Marine 8, one for a Suquamish Tribe Police Boat, with two additional slips to accommodate other vessels in emergency situations, such as a 45-foot USCG response boat. Another feature of this facility includes an above-ground fuel storage facility also built to withstand the impacts of a major earthquake and tsunami. Pairing all of these features with a maintenance facility with a vessel lift would ensure that response boats, possibly including those with the community non-profit Bainbridge Prepares' Flotilla group, are operational and able to support without outside reliance for vessel maintenance.

Identified locations outside of the current privately-owned dock include a site at the City Dock near Waterfront Park. This would reduce the costs of future construction as the property is already city-owned. However, there are significant challenges with building at this location. Water levels at mean low tide are too shallow and would require dredging, which may alter the design of the park. Waterfront Park already serves an important purpose for the community, so any new maritime infrastructure would need to be carefully designed to not impact the space and functionality of the park property. Another potential location would be on the west side of the Washington Ferries Maintenance Facility. This location provides ample deep water for the construction of maritime infrastructure and would benefit from existing security for the facilities. Tsunami impacts from this facility are also lower than the Waterfront Park location, with reduced current speeds and reduced wave heights than other areas of Bainbridge Island, making this location a strong candidate for new response-related maritime infrastructure. Other potential locations can be explored with the focus on response time, land ownership, protection from tsunamis, and security.

This proposed facility could also serve as a tsunami shelter for the ferry maintenance workers for a SFZ earthquake and tsunami, greatly expand the capabilities of local first responders in tsunami response and improve the resilience of the City of Bainbridge Island to tsunamis and other water-related emergencies. The Lead Marine Officer should coordinate closely with the Bainbridge Island Fire Department, Suquamish Tribe, Washington State Ferries, the non-profit Bainbridge Prepares and Washington Emergency Management Division to coordinate on the planning aspects of the project and identify potential funding sources to support the proposal. It should be noted that additional planning considerations will be needed for any Flotilla group members of Bainbridge Prepares to utilize one of the slips, such as a Memorandum of Understanding or other agreement with the city and the ability for members of the public to access the facility.

Move Docks and Assets Away from High Hazard Areas

Feasibility of Mitigation Action: Not Feasible

Bainbridge Island's entire coastline faces tsunami risk from both the Seattle Fault Zone and Cascadia Subduction Zone. There is not sufficient space to move city-owned vessels and infrastructure further into the harbor or anywhere else around the island as the island is already fully zoned and developed. Given the recent installment of the upgraded infrastructure, it would be too costly and time-consuming to move maritime infrastructure when there may be no significant reduction of tsunami risk.

Additionally, moving the wastewater treatment facility out of the inundation zone would be an expensive, time-consuming process. Other mitigation and response actions, such as working with the WWTP staff to develop procedures to shut down operations, would be more feasible to reduce the impacts on wastewater treatment infrastructure.

Widen Size of Harbor Entrance to Prevent Jetting

Feasibility of Mitigation Action: Not Feasible

For Eagle Harbor, widening the size of the harbor entrance would prove to be very challenging and costly. While the city owns the property on the southern side of the mouth of the bay, the northern side is currently private property under residential use. Additionally, the city-owned property is part of the Wyckoff/Eagle Harbor superfund site. Disturbing the seafloor around the mouth of the bay before cleanup of the superfund site is complete risks a tremendous ecological disaster due to the contaminated sediments located there. For these reasons, other tsunami mitigation measures should be targeted before projects that require significant environmental engineering are considered.

Construct Floodgates

Feasibility of Mitigation Action: Not Feasible

Constructing floodgates for Eagle Harbor would require an extremely significant input of labor, coordination, and time. In addition to the challenges in planning, funding, and executing this mitigation measure is the added challenge that building these gates in the most effective location would require disturbing the Wyckoff/Eagle Harbor superfund site. As stated earlier, this is highly cautioned against due to the contamination of the sediments in this location.

Due to the overall drawbacks from pursuing this measure even without considering the challenges posed by the superfund site, other mitigation measures offer better investments of time and money to mitigate the impacts of tsunamis for Eagle Harbor.

Construct Breakwaters Farther Away From the Harbor

Feasibility of Mitigation Action: Not Feasible

Eagle Harbor does not currently have any breakwaters built within its area, nor farther away from it. Building a breakwater would be an expensive and time-consuming effort, requiring significant coordination with an agency such as the U.S. Army Corps of Engineers. In addition, while a more distant breakwater may be able to avoid disturbing the Wyckoff/Eagle Harbor superfund site, it is doubtful the payoff would be worth the significant effort required for construction and potential environmental remediation. Given these barriers to construction, building breakwaters at any distance is not feasible for Eagle Harbor.

Fortify and Armor Breakwaters

Feasibility of Mitigation Action: Not Feasible

Eagle Harbor does not currently have any breakwaters built within its area. Building a breakwater would be an expensive and time-consuming effort, requiring significant coordination with an agency such as the U.S. Army Corps of Engineers. In addition to the project considerations themselves, the Wyckoff/Eagle Harbor superfund site is located near the mouth of the harbor, further restricting any possible construction in the vicinity. Given these significant barriers to construction, building breakwaters is not feasible for Eagle Harbor.

Deepen or Dredge Channels Near High Hazard Zones

Feasibility of Mitigation Action: Not Feasible

Of concern in the Eagle Harbor area is the Wyckoff/Eagle Harbor Superfund Site, located at the southern side of the mouth of the harbor. The site was home to a creosote wood-treating facility that was in operation from 1903-1988 and leaked contaminants into the surrounding soils and groundwater (Environmental Protection Agency [EPA], 2023). The EPA identified the facility as a superfund site in 1987 and began cleanup operations. Although the risk at the site itself has been controlled or eliminated, there continues to be creosote contamination in East

Beach and North Shoal. Cleanup efforts are still ongoing, and restrictions have been put in place to ensure that the areas remain largely undisturbed.

Deepening or dredging within Eagle Harbor would cause major environmental damage and require extensive cleanup operations. This mitigation action cannot be considered until the ongoing cleanup operations by the EPA are complete, which may be a few decades. The city should continue to work with the EPA on the safety of the site and ongoing cleanup efforts as it directly impacts tsunami mitigation and response efforts. Other mitigation actions need to be explored to reduce the impacts of a tsunami for the community.

Section 6: 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. Similarly, it is crucial when planning for other hazards to include tsunami risk in ongoing efforts, so completed projects do not further exacerbate the impacts of a tsunami.

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

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

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

Implementing tsunami mitigation measures requires creativity, financial resources, determination, and community buy-in. The following 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. Recreation Conservation Office (RCO) Grant

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

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

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

2. Hazard Mitigation Assistance (HMA) Programs

FEMA's Hazard Mitigation Assistance (HMA) Programs provide pre- and post-disaster funding to reduce the risks to people and property from natural disasters. This includes funding through 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 or be part of a FEMA-approved Hazard Mitigation Plan (HMP) to be eligible. Projects funded by federal grants will require an environmental and historic preservation review.

- **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. Building Resilient Infrastructure and Communities (BRIC) Grant

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. Port Infrastructure Development Program (PIDP) Grant

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

- **Eligibility**: Public entities that own or operate port facilities, including state and local governments, tribal organizations, and port authorities.
- **Matching Requirements**: Typically requires a match from the applicant, although the percentage varies depending on the scope of the project.

- **Funding Range**: Individual awards can range from $1 million to over $50 million for large-scale port infrastructure projects.
- **Application Period**: Annual, with submission deadlines typically in the summer.

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

5. Rebuilding American Infrastructure with Sustainability and Equity (RAISE) Grant

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. National Coastal Resilience Fund

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

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

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

8. Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT) Grant

Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation is a competitive grant program that prioritizes strengthening surface transportation to be more resilient to natural hazards, including climate change, sea level rise, flooding, extreme weather events, and other natural disasters. This federal funding program has two more years left, with $576M available for this fiscal year and $300M for the final year in 2026.

- **Eligibility:** States, local governments, special purpose districts, Tribes
- **Matching Requirements:** 20% non-federal cost match
- **Funding Range: $**576 million for the fiscal year 2025 and $300 million for 2026

To learn more, visit transportation.gov/rural/grant-toolkit/promoting-resilient-operations-transformative-efficient-and-cost-saving.

9. 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.

10. Coastal Hazards Organizational Resilience Team (COHORT)

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

What COHORT Offers in the Short Term:

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

What COHORT Offers in the Long Term:

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

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

11. Coastal Hazards Resilience Network (CHRN)

The goal of the Coastal Hazards Resilience Network (CHRN) is to strengthen the resilience of Washington's coastal communities through collaboration, education, and knowledge exchange.

This website provides a curated selection of relevant science, best practices, and other resources related to coastal hazards in Washington. CHRN provides communities with webinars, access to a network of resilience practitioners in the state, an annual meeting, a resource library, and many other resources.

Letters of Support for Tsunami Mitigation and Response Initiatives

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

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

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

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

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 7: Conclusion and Next Steps

The maritime community of Bainbridge Island's Eagle Harbor faces significant risks from tsunamis and earthquakes, with potential impacts on infrastructure, vessels, and public safety. These hazards, stemming from both Cascadia Subduction Zone (CSZ) and Seattle Fault Zone (SFZ) scenarios, underscore the importance of proactive planning and mitigation. While these risks pose challenges, they also present opportunities to further enhance the resilience of Eagle Harbor through targeted mitigation measures and refined response strategies.

Bainbridge Island has already demonstrated strong leadership in disaster preparedness, implementing significant infrastructure improvements such as flexible dock systems, strengthened dock pilings, and durable materials designed to withstand tsunami forces. These completed measures serve as examples of how thoughtful design and investment can reduce damage and enhance safety. The innovative Bainbridge Prepares partnership, and its Flotilla initiative provide a unique model for community-driven disaster response, showcasing the power of leveraging local expertise and resources to complement professional emergency management efforts.

Exploring funding opportunities detailed in this document, as well as other state and federal programs, will be essential to advancing these initiatives. Partnerships with agencies such as Washington Emergency Management Division, Washington Geological Survey, and federal entities like FEMA can help secure the resources necessary to implement these projects.

The outlined mitigation and response actions provide a roadmap for enhancing Eagle Harbor's resilience, protecting its maritime community, and preserving its functionality during and after a disaster. By continuing to prioritize preparedness, investing in infrastructure, and engaging with stakeholders at all levels, the City of Bainbridge Island can build on its successes and serve as a model for other coastal communities facing similar challenges. This commitment to continuous improvement will ensure that the city remains ready to meet future hazards while safeguarding the safety and well-being of its residents and visitors.

Cascadia Subduction Zone Tsunami Impacts

The Cascadia Subduction Zone (CSZ) poses a significant earthquake and tsunami risk to the Eagle Harbor area. Capable of producing massive earthquakes up to magnitude 9, the CSZ could generate very strong to severe shaking (MMI 7–8) in Eagle Harbor, compounded by local geological conditions. The resulting tsunami would impact the entire U.S. West Coast, with waves entering the Strait of Juan de Fuca within 20 minutes of the earthquake. The tsunami would travel through Puget Sound, reaching Eagle Harbor approximately 2 hours and 20 minutes later.

Simulations of a CSZ-generated tsunami indicate offshore wave heights of up to 7 feet and significant inundation of Eagle Harbor's shoreline. Flooding depths could range from 3 to 9 feet in low-lying areas, particularly near the Head of the Bay. While the response time offers a critical window for evacuation, the event's scale underscores the importance of preemptive measures and understanding the earthquake's devastating impacts from shaking prior to tsunami wave arrival. Messaging must emphasize evacuation as the safest action, even for boaters, given the risks posed by currents, debris, and potential infrastructure damage.

Infrastructure impacts are expected to include damage to docks, piers, and moored vessels, though tsunami current speeds within the harbor are generally modeled to remain below the extreme damage threshold of 9 knots. Still, localized currents near the entrance of Eagle Harbor could reach hazardous levels, making navigation perilous during the tsunami's active phases.

Seattle Fault Zone Tsunami Impacts

The Seattle Fault Zone (SFZ), which lies directly beneath Eagle Harbor, represents a more localized but highly destructive earthquake and tsunami hazard. A major earthquake on this fault, with magnitudes estimated between 7.2 and 7.5, could produce severe to violent shaking (MMI 8–9) in Eagle Harbor, with significant coseismic land-level changes. Historical evidence from the 923 C.E. Seattle Fault earthquake shows shoreline changes of up to 23 feet of uplift and 3 feet of subsidence.

A tsunami generated by an SFZ earthquake could reach Eagle Harbor in less than 10 minutes, leaving little time for evacuation. Offshore wave heights are modeled to peak at 23 feet, with onshore inundation depths exceeding 20 feet near the shoreline. This would lead to substantial destruction of maritime infrastructure, including capsizing vessels, damaged pilings, and widespread debris. The tsunami's rapid arrival, combined with violent water-level fluctuations and strong currents exceeding 9 knots throughout Eagle Harbor, makes immediate evacuation to high ground imperative for safety.

Possible coseismic subsidence further exacerbates the risks, permanently altering the shoreline and increasing vulnerability to daily tidal flooding. These changes would have long-term implications for recovery efforts, potentially displacing residents and businesses in low-lying areas. Given the tsunami's speed and intensity, evacuation by boat is not feasible in an SFZ event, and all individuals in affected zones should prioritize moving inland as soon as the shaking stops.

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 City of Bainbridge's tsunami response capabilities. However, some response actions warrant further review to assess their suitability for the city, particularly in the context of timing before wave arrival and protective action messaging. Achieving effectiveness in these response actions will necessitate additional time, research, and planning. Although certain actions may be deemed unfeasible by the city, 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 City of Bainbridge, categorized by feasibility and the need for review:

Feasible Response Measures

1. **Identify Boat Owners/Individuals Who Live Aboard Vessels and Establish Notification Processes**
   The Emergency Management Coordinator should collaborate with the community non-profit Bainbridge Prepares, Flotilla leads, and marina personnel to enhance communication with liveaboards and visiting boaters. By aligning with the Wildfire Response and Evacuation Plan, The Emergency Management Coordinator can develop a robust tsunami-specific notification process and exercise it to ensure clarity and preparedness among all stakeholders.

2. **Evacuate Public and/or Vehicles from Waterfront Areas**
   Efforts should focus on pedestrian evacuation and not vehicular evacuation of vehicles from the waterfront. Existing frameworks, such as the Wildfire Response and Evacuation Plan, offer valuable templates for evacuation and public communication. Regular public drills and educational initiatives will strengthen community preparedness.

3. **Personal Flotation Devices/Vests for Marina Staff**
   The availability of personal flotation devices (PFDs) for marina staff is a proactive safety measure. The Emergency Management Coordinator and the Lead Marine Officer should ensure adequate supplies of PFDs, particularly for Marine 8 operations.

4. **Informing and Coordinating with Key First Responders During a Tsunami**
   Establishing a comprehensive earthquake and tsunami communication plan between The Emergency Management Coordinator, Bainbridge Police, and other agencies is critical. Exercises such as WA EMD’s state-led tsunami drills and PACIFEX provide opportunities to refine these protocols. The community non-profit Bainbridge Prepares’ trained volunteer network, which includes the Flotilla, can possibly supplement professional responders, ensuring comprehensive coordination.

5. **Activate Incident Command at Evacuation Sites**
   The relocation of the EOC to the Ted Spearman Justice Center enhances the city's ability to manage tsunami response. Establishing Incident Command structures at evacuation sites, supported by ICS-trained personnel, will provide clear leadership and reduce chaos.

6. **Activate Mutual Aid System as Necessary**
   Formal agreements with neighboring jurisdictions and community organizations like the non-profit Bainbridge Prepares provide a strong foundation for mutual aid. These partnerships enable rapid resource sharing and coordination.

7. **Pre-Identify Personnel to Assist in Rescue, Survey, and Salvage Efforts**
   The community non-profit Bainbridge Prepares’ Flotilla group exemplifies how volunteer networks can enhance post-tsunami recovery efforts. Providing comprehensive training for volunteers and responders in tools like drones and Survey123 will ensure accurate and efficient damage evaluation.

8. **Secure Moorings of City-Owned Vessels**
   Properly securing Marine 8 and educating private vessel owners on effective mooring techniques are essential steps. Public education campaigns, in collaboration with WA EMD, can provide vessel-specific guidance to enhance preparedness.

Response Measures Needing Review

1. **Shut Down Port Infrastructure Before Tsunami Arrives**
   The lack of established SOPs for shutting down private infrastructure poses challenges. The Emergency Management Coordinator should collaborate with private marina owners to draft MOUs that outline shutdown procedures. Coordination with Puget Sound Energy and the Wastewater Treatment Plant on integrating Earthquake Early Warning systems may improve infrastructure resilience.
2. **Move Vessels Out of the Port**
   Current challenges include insufficient authority over private vessels and the dangers posed by high current speeds. WA EMD can facilitate discussions with the U.S. Coast Guard and maritime stakeholders will help establish guidelines and determine the feasibility of this action.
3. **Restrict Traffic Entering the Marina by Land and Aid in Traffic Evacuation**
   Effective traffic control requires pre-planning and resources that are currently limited. Coordination with Public Works and CERT volunteers will be essential to manage traffic during evacuations. Developing adaptable strategies for post-earthquake scenarios, including alternate routes and temporary barriers, will enhance feasibility.
4. **Pre-Stage Emergency Equipment Outside Affected Area**
   The ongoing development of the new EOC and reliance on off-island resources present logistical hurdles. The Emergency Management Coordinator should inventory critical equipment and identify safe staging locations. Collaborating with the community non-profit Bainbridge Prepares and maritime partners to pre-plan transportation and equipment deployment will address these challenges.

Further, the city 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 maritime tenants and other users of the maritime 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 city 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 city save lives, protect property, and shorten recovery times.

Recommended Mitigation Actions

To help mitigate potential damage to maritime infrastructure, tenant property, and reduce potential casualties, it is recommended that the city 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 city's facilities. 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.

Notably, several measures have already been marked as "complete," serving as examples of successfully mitigated infrastructure improvements. These completed actions highlight effective strategies for reducing tsunami-related risks and provide a valuable benchmark for other marinas, ports, and harbors seeking to enhance their infrastructure resilience against tsunami hazards. By showcasing these completed measures, the city can demonstrate practical, achievable steps that other maritime communities can emulate in their efforts to mitigate tsunami risks.

Completed Mitigation Measures

- **Increase Flexibility of Interconnected Docks and Dock Fingers and Improve Flotation of Docks**
  The 2019 upgrades to the city dock included flexible connections between dock floats, utilizing aluminum frames and polyethylene foam-filled float tubs for enhanced durability and adaptability. This design mitigates tsunami impacts by allowing freedom of movement and improving dock stability during water-level changes.
- **Increase Size and Stability of Dock Piles/Increase Height of Piles to Prevent Overtopping**
  Steel pilings installed during the 2019 city dock upgrades were designed to withstand expected wave heights from a Cascadia Subduction Zone (CSZ) tsunami. The pilings were anchored deeply and built to heights that consider sea-level rise and tsunami hazards.
- **Strengthen Cleats and Single Point Moorings**
  Upgraded aluminum cleats, installed in 2019, enhance the security of vessels during tsunami events. The infrastructure accommodates various vessel sizes and demonstrates an effective approach for communities seeking to upgrade cleats for improved resilience.
- **Improve Movement of Dock Along Dock/Pilings**
  Recent infrastructure updates included pile hoops and rub strips that allow docks to move freely along pilings during rapid water-level changes. This design minimizes the risk of docks jamming against pilings and reduces potential damage during a tsunami.

Feasible Mitigation Measures

- **Install Tsunami Signage**
  The City of Bainbridge Island can enhance existing signage with tsunami-specific information, including evacuation routes and alert procedures. Coordination with Washington State Ferries for displaying tsunami information in terminals is also feasible.
- **Debris Deflection Booms to Protect Docks**
  Deploying debris booms during distant tsunami threats is a cost-effective way to mitigate infrastructure damage. Strategic placement can channel debris to specific areas, reducing clean-up time and disruption to maritime operations.

Mitigation Measures Needing Review

- **Reduce Exposure of Petroleum/Chemical Facilities and Storage**
  Relocating the wastewater treatment plant and pump stations out of the inundation zone is a complex potential mitigation measure. Collaboration with facility staff to develop shutoff procedures and identify vulnerable infrastructure is essential. Addressing risks from the Eagle Harbor/Wyckoff Superfund site requires coordination with the EPA to prevent environmental contamination during a tsunami.
- **Acquire Equipment/Assets to Assist in Response Activities**
  Developing a tsunami- and earthquake-resistant dock for emergency response vessels is under consideration. Features would include durable materials, multiple slips for various agencies, and above-ground fuel storage. Coordination with multiple stakeholders is necessary to identify funding sources and determine the dock's location and design. This facility could also support the community non-profit Bainbridge Prepares' Flotilla group and serve as a tsunami shelter for ferry maintenance workers.

Additionally, the city 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 city's long-term planning, the city 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 city 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 city's maritime facilities will help ensure that tsunami hazards and risks are widely understood by those who occupy and utilize the city's property. Helping tenants understand the dangers posed by tsunami waves and encouraging them to take steps to mitigate that risk will help the city become more resilient overall and assist in recovery efforts.