Tsunami Maritime Response and Mitigation Strategy - Port of Bellingham

Bellingham, Washington

Tsunami Maritime Response and Mitigation Strategy

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DISCLAIMER: The developed report has been completed using the best information available and is believed to be accurate; however, its preparation required many assumptions. Actual conditions during a tsunami may vary from those assumed, so the accuracy cannot be guaranteed. Tsunami currents will depend on specifics of the earthquake, any earthquake-triggered landslides, offshore construction, and tide level, and thus the tsunami current locations may differ from the areas shown on the maps. Information on the maps is intended to permit state and local agencies to plan emergency procedures and tsunami response actions. The Washington Emergency Management Division makes no express or implied representations or warranties (including warranties of merchantability or fitness for a particular purpose) regarding the accuracy of this product nor the data from which the tsunami current maps were derived. In no event shall the Washington Emergency Management Division be liable for any direct, indirect, special, incidental, or consequential damages with respect to any claim by any user or any third party on account of or arising from the use of this report.

Executive Summary

The state of Washington has the second highest earthquake risk in the nation. Western Washington has several active local earthquake faults that could impact communities along the coastlines on both the outer Pacific coast and inland waters of the Salish Sea including the Puget Sound. The seven-hundred-mile-long Cascadia Subduction Zone (CSZ) lies just off the Pacific Ocean coastline of Washington and runs from northern California up to Vancouver Island, BC Canada. The CSZ is capable of generating a powerful magnitude 9+ earthquake, which could shake for up to 5 or 6 minutes. Earthquakes and landslides are the main source of tsunamis in Washington. A local CSZ earthquake-generated tsunami is capable of creating 60+ foot waves that could hit the Pacific coast of Washington within just 15-20 minutes after the earth started to shake. The tsunami, which is made up of a series of waves, will strike the outer coast then travel into the Strait of Juan de Fuca and inner coastal waters. This series of waves will bring impacts to the coastal areas of the Salish Sea within a few hours of the start of the earthquake and can last over 12 hours. Distant tsunamis, for example those originating in Japan or Alaska, would have significantly longer warning times (greater than 3 hours) and would likely bring less severe impacts.

Among the most vulnerable facilities to tsunami impacts are ports, which are typically located along shorelines in developed areas. They are often built on land created from dredged soil and are thus susceptible to liquefaction in addition to tsunami impacts. Ports are a vital component of the maritime industry, which is comprised of key infrastructure for transportation, travel, and commerce. Ports provide and operate commercial marine transportation facilities that ship a wide spectrum of commodities ranging from grain (bulk) to container cargoes. Ports also maintain and operate airports, commercial and pleasure boat marinas, subsidized space for start-up businesses, cold-storage plants, log-export yards, boat launch ramps, and even short-haul railroads. The maritime industry in Washington is a $21.6 billion industry contributing directly and indirectly to 146,000 jobs and $30 billion in economic activity.

The ability of ports to withstand a disaster and resume operations quickly will be a major factor in the recovery of the local community and economy in the short and long term. One way to help is to develop a strategy with recommended actions that can be implemented to increase port resilience. Contained within this document is the tsunami maritime response and mitigation strategy for the Port of Bellingham's facilities around Bellingham Bay including response guidance in the event of tsunamis for Small Craft (Vessels under 300 gross tons) such as recreational sailing and motor vessels, and commercial fishing vessels.

Document Layout

The introduction begins by explaining what a tsunami is, and the differences between local source and distant source tsunamis. It then provides a brief overview of the hazards the maritime community faces from tsunamis. Finally, it provides an overview of the Port of Bellingham.

Section 1 covers the maritime risk from local and distant source tsunamis and provides a brief overview on how to respond during a tsunami. It then explains the different tsunami alert levels and the different ways people can get alerted for tsunamis. This includes the natural warning signs.

Section 2 focuses on recommended response actions and who is responsible for performing them. This information is designed to be applicable to any maritime facility, organization, or community that faces tsunami related hazards. Some examples include evacuating people to high ground and restricting people from entering the tsunami inundation zone.

Section 3 explains mitigation measures for the Port of Bellingham. It covers site-specific mitigation measures that can be undertaken to allow the port to become more resilient in the event of a tsunami. Some example mitigation actions include strengthening cleats and moorings, installing tsunami signs, and increasing the height of dock piles.

Finally, the appendices provide additional information and resources, many of which are specific to the Port of Bellingham. These resources include response checklists, harbor information, graphics, and other detailed information.

Introduction

An earthquake strikes. The ground shakes. If you are on land, windows and doors rattle. Pictures start to fall off the wall. Because you have practiced in drills like the Great Washington ShakeOut, you immediately drop, cover, and hold on. Books fall and bookshelves topple. You hear car alarms go off. Windows break. The shaking seems to go on forever but then it finally stops. You get up, check your surroundings to make sure it is safe, and help your family members. You immediately follow the nearest tsunami evacuation route, just like you practiced, because you live or work in a tsunami zone. If you are on your vessel, you see trees, telephone poles and buildings sway dangerously back and forth. Windows break and bricks fall off the sides of buildings. Aware of the dangers of being at sea during a tsunami you know to immediately head for shore. Without delay you dock and secure your vessel, leaving to follow your tsunami evacuation route. The streets are cracked and buckled. Trees and powerlines have fallen down, so you walk with caution. Because you and the maritime community have implemented a tsunami maritime response and mitigation strategy, you and your family know what to do to protect yourselves when you are in your vessel and/or at the Port of Bellingham. You get to high ground. As you look out towards the water, you see a powerful tsunami wave racing to shore, smashing everything in its path, the first of several life-threatening waves. Thankfully, you, your family, and your neighbors are safe.

The introductory scenario demonstrates the value of developing and implementing a tsunami maritime response and mitigation strategy. This strategy provides practical guidance to assist your maritime community in reducing your tsunami risk. You may be a community leader, an elected official, a concerned resident, a business owner, an employee, a government worker, or some other member of the community. Whatever your role in the community, we hope this strategy will assist you in your efforts to make your community safer.

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, and by meteor impacts into a body of water. 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.

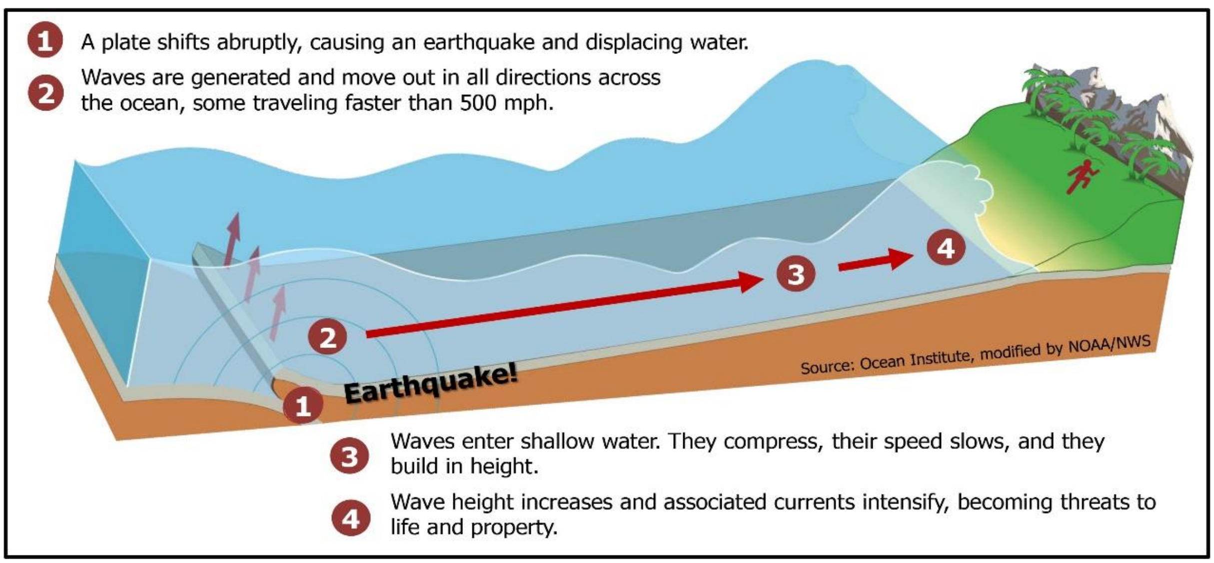
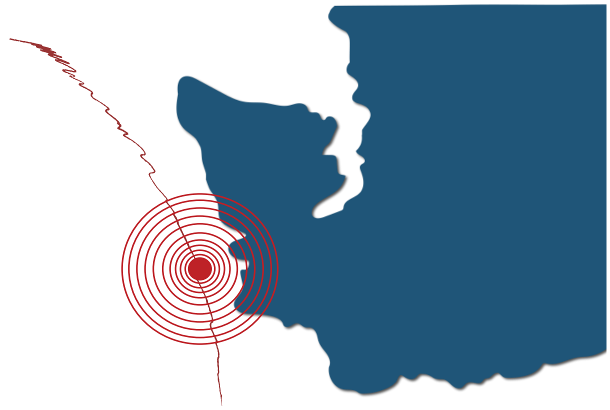


Figure 1: Earthquake generated tsunami diagram.

Tsunamis triggered by earthquakes pose the greatest threat 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



Local source tsunamis are tsunamis for which the first waves arrive at a location in under 3 hours. Large underwater earthquakes at the Cascadia Subduction Zone (CSZ), at other local faults, or landslides are the most likely cause of local source tsunamis, which can produce significant damage in harbors and bays. A local source tsunami may strike in less than an hour, and sometimes in only minutes, which significantly affects the ability of local authorities to respond and of the public to evacuate. For local tsunami sources it is impossible to predict how soon the initial wave might strike; it could even occur while the ground is still shaking from the earthquake.

A locally generated earthquake on the CSZ could produce catastrophic tsunami waves that hit outer coast shores within minutes. Inundation in the low-lying parts of the Northern Inland Waters and Puget Sound will follow within two hours. Strong currents and water level changes would continue for tens of hours after first arrival. A locally generated earthquake on another local fault (e.g., Seattle fault) could generate a tsunami wave that will inundate the shores of the Puget Sound within minutes depending on the fault location. Strong currents and water level changes within the Sound would continue for hours after the first wave arrival. Additionally, the earthquake shaking has the potential to cause slope failures leading to landslide-induced tsunamis with no warning and immediate effects.

Distant Source Tsunamis

Distant source tsunamis are tsunamis for which the first waves arrive at a location in over 3 hours. Distant source tsunamis are most frequently caused by large underwater earthquakes in other parts of the world and can cause significant damage near their sources. The source of a distant tsunami greatly affects the ability of local governments to respond and the public to mitigate expected impacts. For example, a tsunami originating in or near Japan (9-10 hours wave travel time away) or Chile (14-16 hours away) provides more time for local response activity than a tsunami originating off the coast of Alaska (4-6 hours away). Alaska is Washington’s closest and therefore biggest threat for a distant source tsunami.

Tsunami Hazards for Mariners and Vessels

Tsunamis pose many significant hazards for boaters and their vessels. Sudden large fluctuations in the water level can cause unprepared and unaware vessels to become quickly swamped with water and/or washed onto the shore. In shallow areas these fluctuations can also ground vessels on the sea floor when water rapidly recedes, only to be overtopped by water when the next wave rapidly arrives (Figure 2). These incoming and receding surges of water can also create large tsunami bores that can capsize boats and complex coastal waves that pose a danger to navigation (Figure 3).

Figure 2: Damage in Crescent City, California, from the 2011 Japan tsunami, about 10 hours after the initial earthquake.

Figure 3: Standing tsunami bore wave in Sunaoshi River, Miyagi Prefecture, Japan 2016. Miyagi Prefectural Police/Kyodo/via Reuters

Figure 4: Whirlpools forming off Japan's coast after the 2011 tsunami. Yoiumri / Reuters

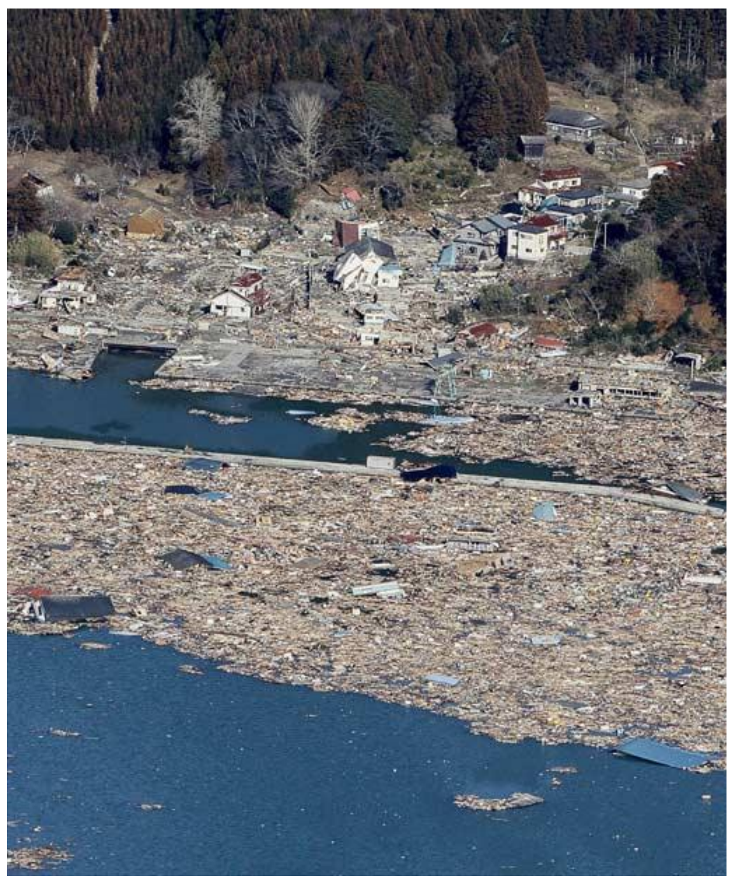


Figure 5: Tsunami debris in the water after 2011 tsunami in Ishinomaki, Japan. Koyodo News / AP

Tsunami events can create strong and dangerous currents with speeds greater than 9 knots 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 4) 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 also drag massive amounts of dangerous debris into the water (Figure 5).

All the above risks also exist inside of harbor and port areas. The extreme water level fluctuations have the potential to make docks overtop pilings, become detached from the shore or sea floor, or break apart in sections (Figure 6). Vessels can be grounded when water recedes. Large, deep keeled vessels can experience strong drag sufficient to rip them from their moorings or lift them on top of docks or the shore (Figure 7). Narrow entrances to harbors can amplify current speeds and cause water to move in unexpected directions. The confined nature and amount of infrastructure and vessels in harbors can lead to a massive amount of debris moving through the area, creating dangerous conditions. All these hazards can exist for 12-24 hours or more after the start of the event.

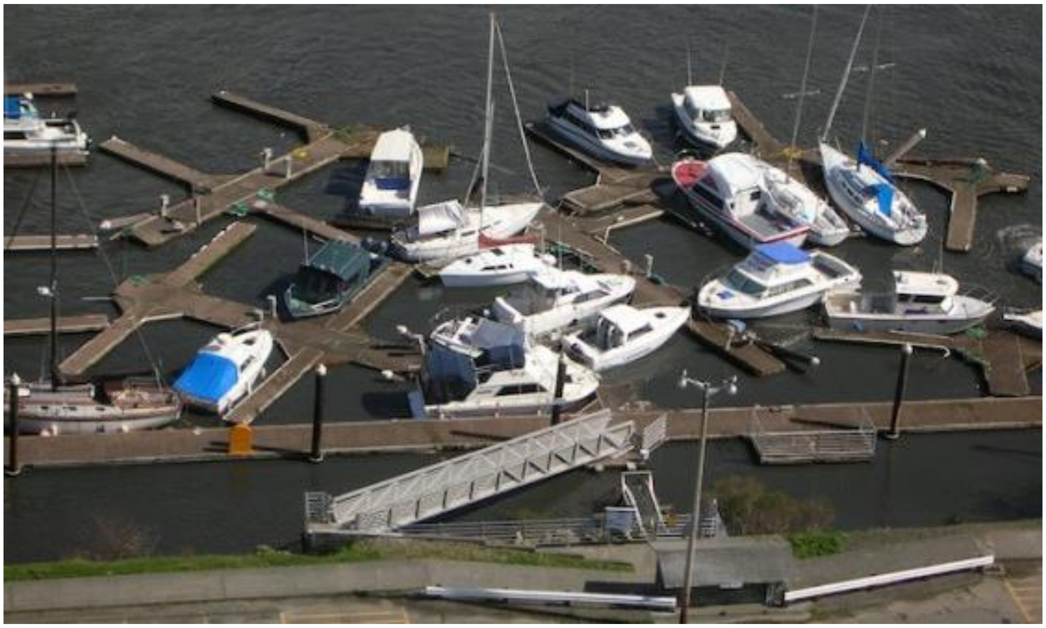


Figure 6: Docks broken from Japan 2011 distant tsunami event in Brookings, OR. USCG Photo by Group Air Station North Bend

Figure 7: Ship lifted on to land by tsunami waves in Japan. US Navy photo

Summary of Tsunami Hazards that can Directly Affect Boats:

- Severe water-level fluctuations
    - Docks could overtop piles as water level rises
    - Vessels could be 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 inexperienced and unprepared boaters who take their boats offshore

Boater Considerations During a Tsunami Event

Mariners and vessel captains will need to take into consideration many factors if they are at sea during a tsunami event. 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 event or to instead return to shore, secure their vessel and evacuate to high ground. Some things to consider include: the distance to shore or deep water (100 fathoms or 600 foot depth); the skill level of the captain and crew; the vessel speed and capability; the draft of the vessel; the amount of provisions, fuel, and equipment on board; current weather, tide stage and conditions on the sea; the amount of time before the tsunami impact; and whether the vessel has adequate communication with other nearby vessels and authorities on shore.

Keep in mind that while there may be some areas in the Salish Sea and Puget Sound where the water is deep enough (600 feet) to be considered "safe", they will be hard to find, and these minimum water depth recommendations are for the open ocean. The narrow and complicated structure of the inner coast waterways mean tsunami waves and currents will behave quite differently than they would in the open ocean. It is possible that no areas within the Salish Sea, which includes the Puget Sound, are truly safe. Due to this uncertainty it is recommended that vessels not already out on the water remain docked and that people near the water get to high ground immediately. Do not attempt to go out onto the water when a tsunami is on its way toward you.

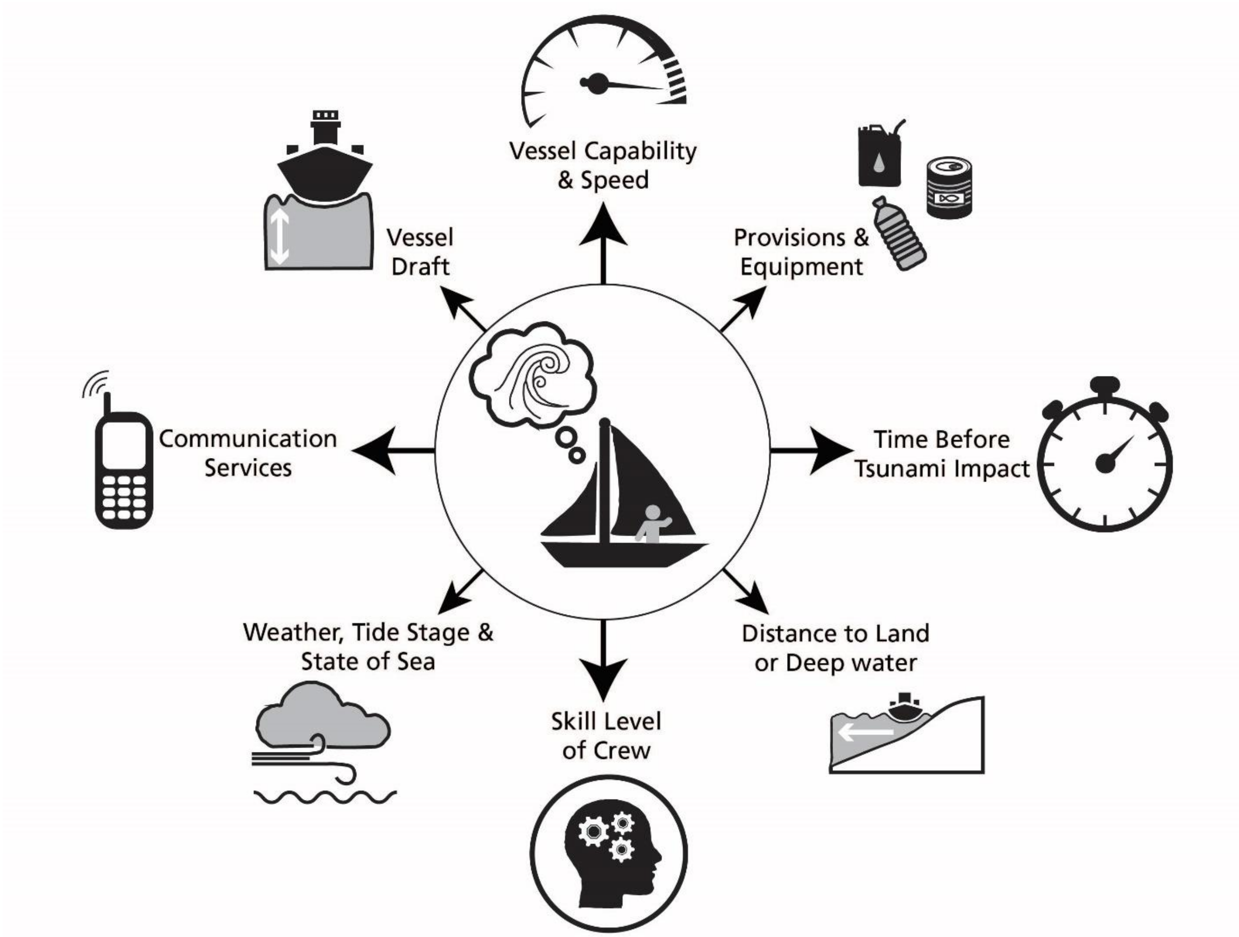


Figure 8: Considerations for boaters who are already offshore during a tsunami.

The Port of Bellingham

The Port of Bellingham (the Port) is located in the heart of downtown Bellingham's waterfront. The Port is a county-wide municipal corporation with a mission to promote sustainable economic development, optimize transportation gateways, and manage publicly owned land and facilities to benefit Whatcom County. The Port of Bellingham also holds the associate development organization (ADO) status for Whatcom County, which is administered through its economic development division, the Regional Economic Partnership (REP). As such, REP functions as the local arm for the Washington State Department of Commerce and is responsible for economic development for all of Whatcom County.

Throughout Whatcom County the Port owns, operates, and maintains approximately 1,600 acres of property including a shipping terminal, the Bellingham Cruise Terminal, two marinas (Bellingham and Blaine), industrial development areas (Sumas), commercial uplands, parklands, shoreline public access areas and the Bellingham International Airport (BLI). The Bellingham Cruise Terminal is the southern end of the Alaska Marine Highway System (AMHS), a ferry service operated by the state of Alaska. The AMHS is part of the National Highway System and plays a key role in transport of people and automobiles between the contiguous US and the State of Alaska. The Port supports maritime related business including boat manufacturing and repair, seafood processing, and cold storage. For more information about the Port of Bellingham, please visit https://www.portofbellingham.com/

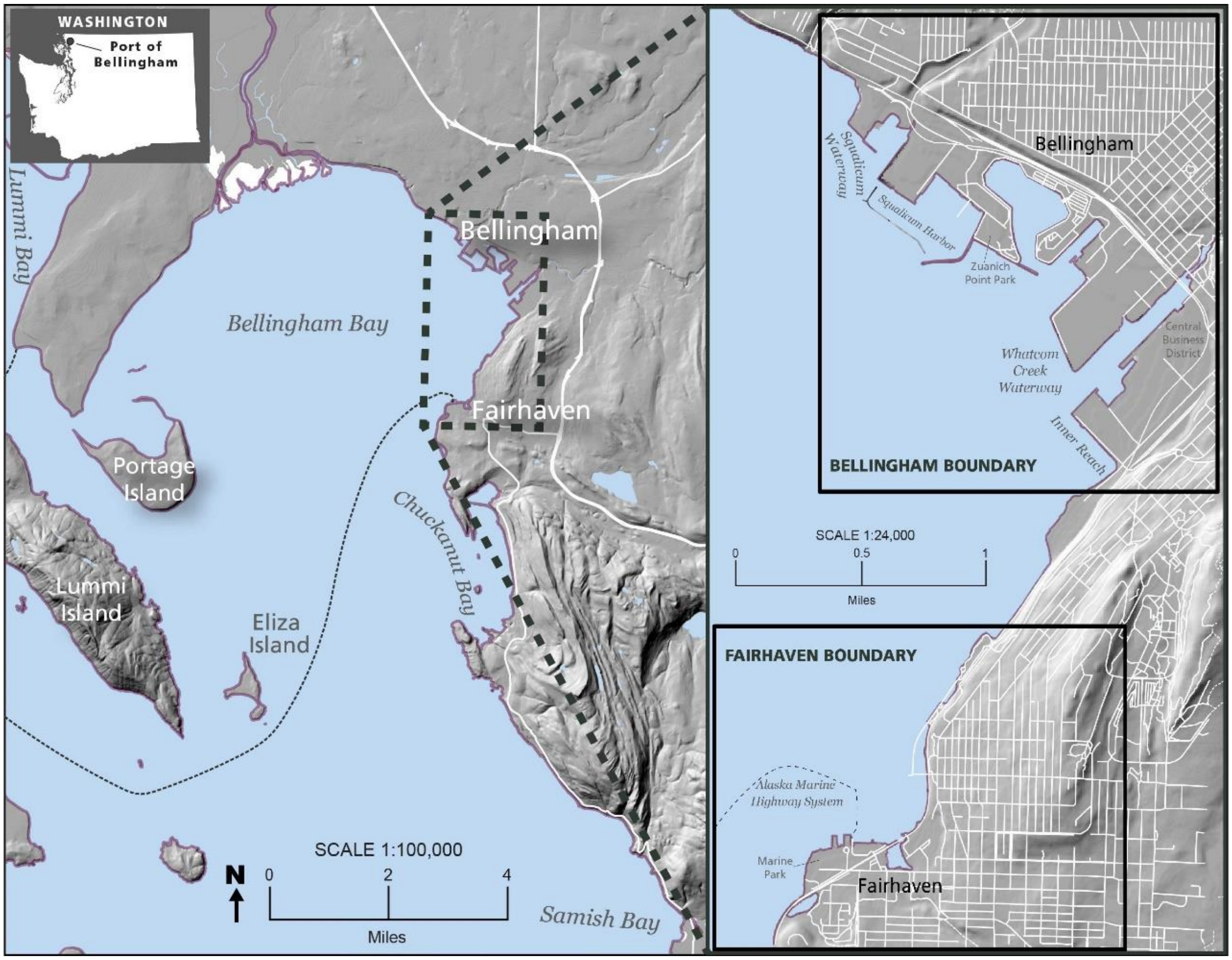


Figure 9: Map of the Bellingham area with close up of port and Fairhaven Terminal areas. Close up boundaries represent modeling study area extents.

The Port of Bellingham properties along the waterfront in the City of Bellingham, as well as the properties in the Fairhaven district, have been identified as being at risk of inundation and damage from a tsunami event. The extent of inundation and damage varies greatly depending on the location and size of the initial event which causes a tsunami. The guidance that follows is based upon maximum considered events for a CSZ event (local) and an Alaska event (distant) and the anticipated effects of those events. This guidance focuses on the specific port properties located on Bellingham Bay in the Bellingham and Fairhaven areas depicted in figure 9. These properties include the Inner and Outer basins of Squalicum Harbor, the Bellingham Shipping Terminal (BST), and the Bellingham Cruise Terminal, as well as the associated surrounding infrastructure.

Do Your Homework

The Washington Emergency Management Division encourages maritime communities to utilize this strategy to help reduce their risk from tsunamis and save lives. The information within this strategy could be used to learn about maritime tsunami risk, incorporate real-time response actions into standard operating procedures, determine and prioritize mitigation measures, and identify additional resources. Although these products, strategies, and related mitigation efforts will not eliminate all casualties and damages from future tsunamis, they will provide a basis for reducing future impacts on life-safety, infrastructure, and recovery in Washington maritime communities. For detailed information on tsunami hazards in your area, check out the Washington Department of Natural Resources Washington Geological Survey (WGS) website. The Washington Emergency Management Division also provides information about tsunami threats in Washington, and general tips on preparedness. For additional information on tsunami maritime hazards consult http://www.tsunami.noaa.gov.

Section 1: Tsunami Maritime Risk and Guidance

Tsunamis can strike without warning and the danger can be even higher for those at sea when a tsunami is coming. Dangerous currents, extreme water level changes, debris in the water, and damage to ports and shore side infrastructure can all lead to potentially fatal situations. The safest place to be when a tsunami strikes is on land at an elevation above the tsunami inundation zone. This underscores the importance of being aware of the natural warning signs a tsunami may be coming, as well as having a way to receive official alerts of a distant source tsunami arrival.

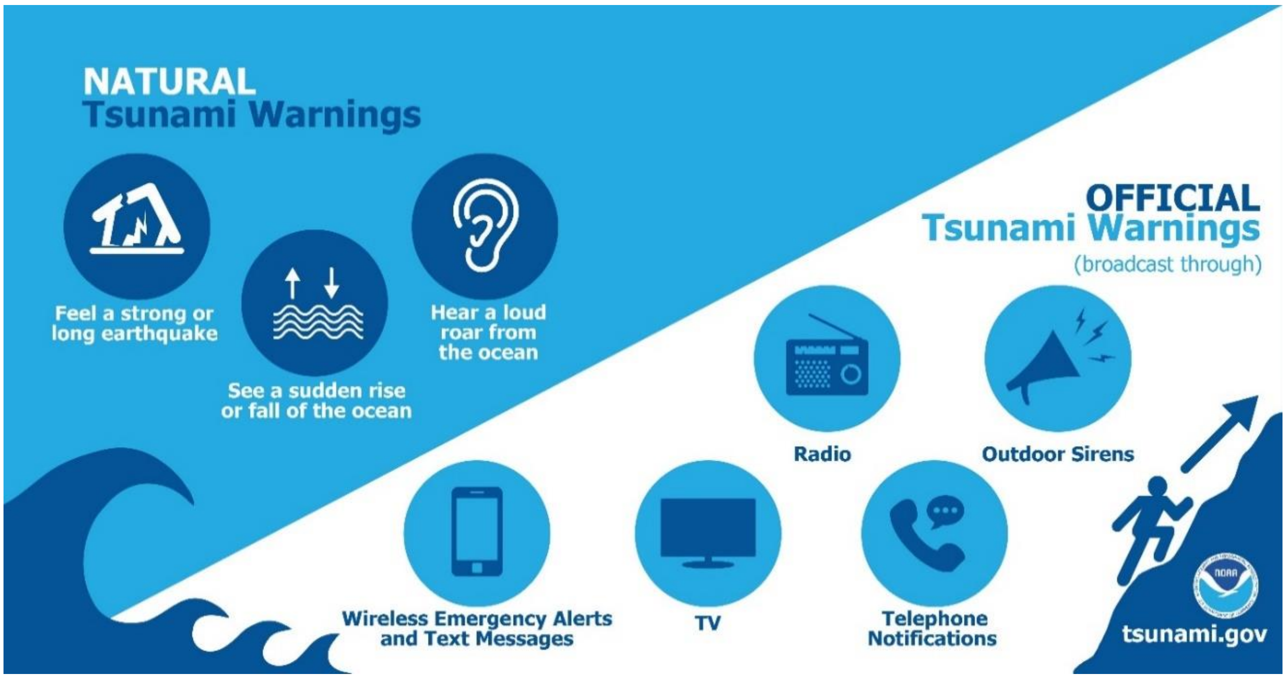


Figure 10: Natural and official warnings

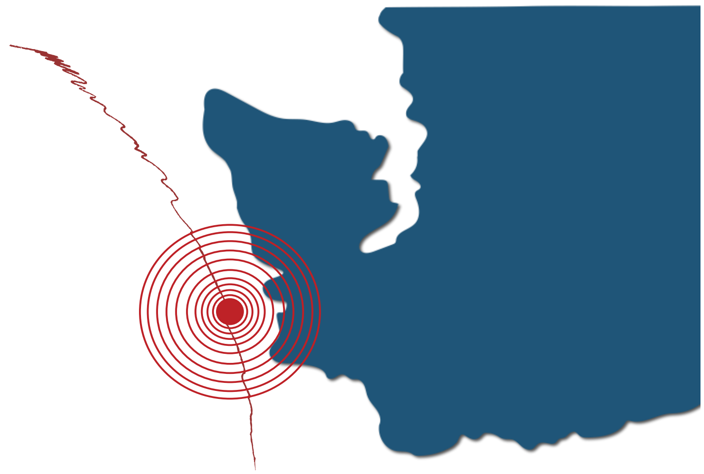
A local tsunami will leave very little time for mariners at sea to take protective action, which is why knowing the natural warning signs is so important. Upon seeing or experiencing any of the natural warning signs that could indicate a tsunami, immediate action should be taken to reach shore, safely dock your vessel and evacuate the inundation zone.

A distant tsunami will leave more time for protective action to be taken, but there will be no obvious signs to warn mariners about the approaching tsunami. The only warning for a distant tsunami will come from official sources. For that reason, mariners should always be equipped with a way to receive alerts while at sea. While having a single way to obtain alerts is good, having multiple redundant ways to receive alerts is recommended.

This document provides response guidance in the event of tsunamis for **small craft** (vessels under 300 gross tons) such as recreational sailing and motor vessels, and **commercial fishing vessels.**

Guidance for Local Source Tsunamis

Maritime response guidance in this section is based on effects of the maximum considered local CSZ-generated tsunami event. Other local source tsunamis generated on other faults may also occur and are likely to have different effects, depending on source and distance, than the maximum considered scenario. Always check with local authorities for more specific guidance that may be appropriate for other local tsunami events.



In a local tsunami event, it is necessary to evacuate the tsunami inundation zone as soon as possible. Any response actions taken should be prioritized based on life safety preservation.

Local Source Tsunami Risk for the Port of Bellingham

A locally generated tsunami from the CSZ will bring major impacts to the Port of Bellingham properties located on Bellingham Bay including:

- Extreme water level changes
- Extensive inundation of dry land
- Major drawdown of water levels exposing the sea floor near shore
- Rapid and powerful current flows
- The first wave most likely will not be the largest or most dangerous
- Significant amounts of loose debris moving unpredictably in the water

In order to prepare for such an event a CSZ generated 9.0 event was simulated and modeled for its impacts. This model includes a surface-rupturing splay fault structure that amplifies tsunami waves. Washington State has adopted this scenario as the “maximum considered case" (called the CSZ-L1 model) for many inundation modeling studies and subsequent evacuation map development. The scenario represents a full rupture of the CSZ extending northward past the entrance of the Strait of Juan de Fuca. The CSZ-L1 model creates very large waves along the Pacific coast, in addition to substantial waves that propagate through the Strait of Juan de Fuca and into the Strait of Georgia, eventually affecting the entire Salish Sea. The first wave crests reach the Bellingham Waterfront about an hour after the initial water level drawdown (about two hours after the earthquake). This model was used to develop maps of inundation, minimum water levels, and current velocity for the areas of Squalicum Harbor, the Bellingham Shipping Terminal, and the Bellingham Cruise Terminal in Fairhaven. It should be noted that, while this scenario constitutes the maximum considered local event, other local sources such as crustal earthquakes or earthquake-induced landslides could cause tsunamis with effects arriving much quicker than a CSZ event.

Anticipated Water Level Changes from a Local CSZ Tsunami Event

Modeling of a CSZ 9.0 earthquake generated tsunami indicates that significant portions of Squalicum Harbor, the Bellingham Shipping Terminal, and surrounding areas will be inundated by water. The flow depth of the inundation on land ranges from slightly more than a foot to depths in excess of 10-16 feet in some locations.

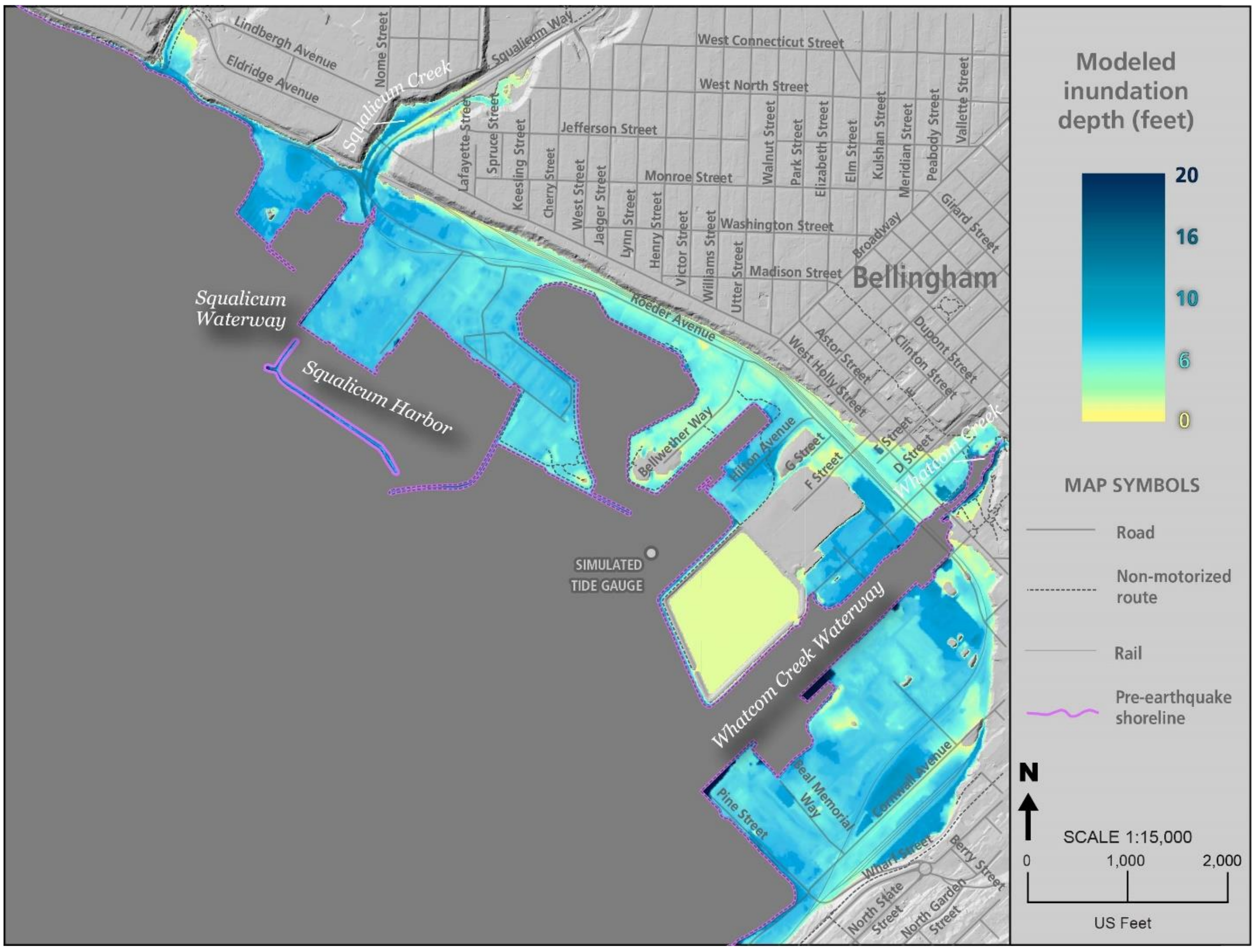


Figure 11: Modeled inundation depth from a tsunami generated by the Cascadia subduction zone (CSZ) L1 scenario in Bellingham.

At the Bellingham Cruise Terminal location significant inundation is expected throughout the terminal area. The flow depth is anticipated to exceed 16 feet at the Alaskan Marine Highway System docks and other docks nearby. The surrounding land up to Harris Ave is anticipated to be flooded at a depth of 1-10 feet or more.

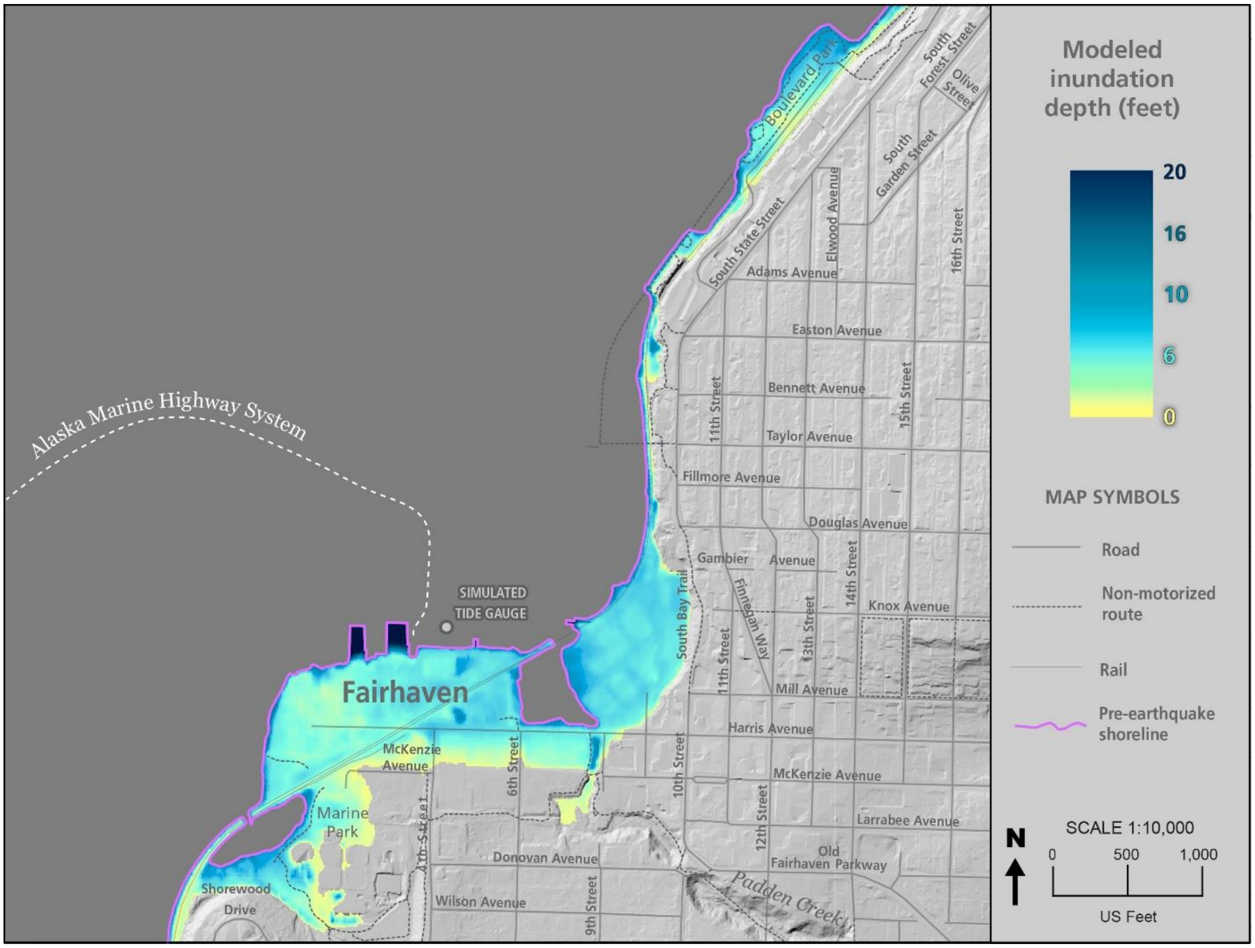


Figure 12: Modeled inundation depth from a tsunami generated by the Cascadia subduction zone (CSZ) L1 scenario in Fairhaven.

Evacuation from the Inundation Zone

Given the amount and extent of inundation from a locally generated tsunami event, all people should immediately evacuate the inundation zone. Evacuees should always plan to evacuate on foot due to the potential for damage to road infrastructure, downed powerlines, and congestion and confusion on the roadways. Pedestrian evacuation maps with approximate walk times (based on a walking speed of 2.46 miles per hour, roughly a 24 minute per mile pace) have been developed for both the Port of Bellingham and Fairhaven areas. Those who work, live, or frequent these areas should study these maps to determine the ideal and most expedient route out of the area and to safety on high ground. Once the optimal routes are determined they should be practiced often to understand the amount of time evacuation will take, and to ensure that evacuation can be performed without delay at any time, day or night, and in any type of weather conditions. For full-sized inundation and evacuation maps for other locations see the Washington Department of Natural Resources [Tsunami Evacuation Maps webpage.]

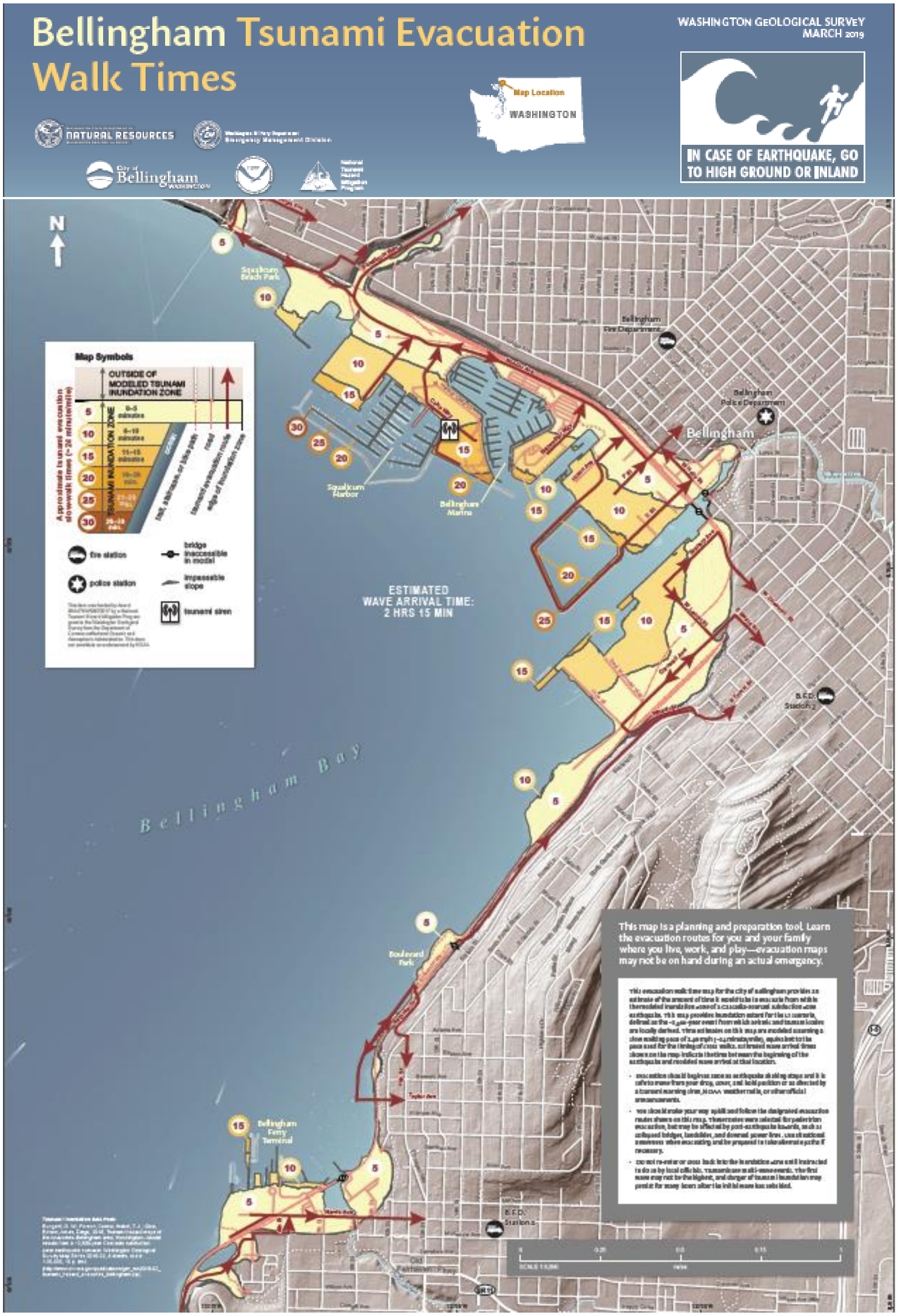


Figure 13: Evacuation Walk Map for Bellingham and Fairhaven areas for a CSZ-L1 scenario.

Minimum Water Level Leading to Possible Exposure of Sea Floor

The simulation of a CSZ event anticipates multiple drastic drawdowns of water during the event, the severity of which will be affected by the tide stage at the time. At the areas around Squalicum Harbor and the Bellingham Shipping Terminal, the simulation shows that regardless of the tide stage the drawdown occurring at around 4 hours after the start of the event will be so severe it will expose the sea floor extensively and for a significant amount of time. This means vessels in the Squalicum Harbor area will become grounded and left resting on the floor of the sea. The following minimum water level maps are modeled based on Mean Low Water, meaning that the time of minimum water depth coincides with the mean lowest tide. This provides the most conservative estimate of the minimum level of water remaining in the study area.

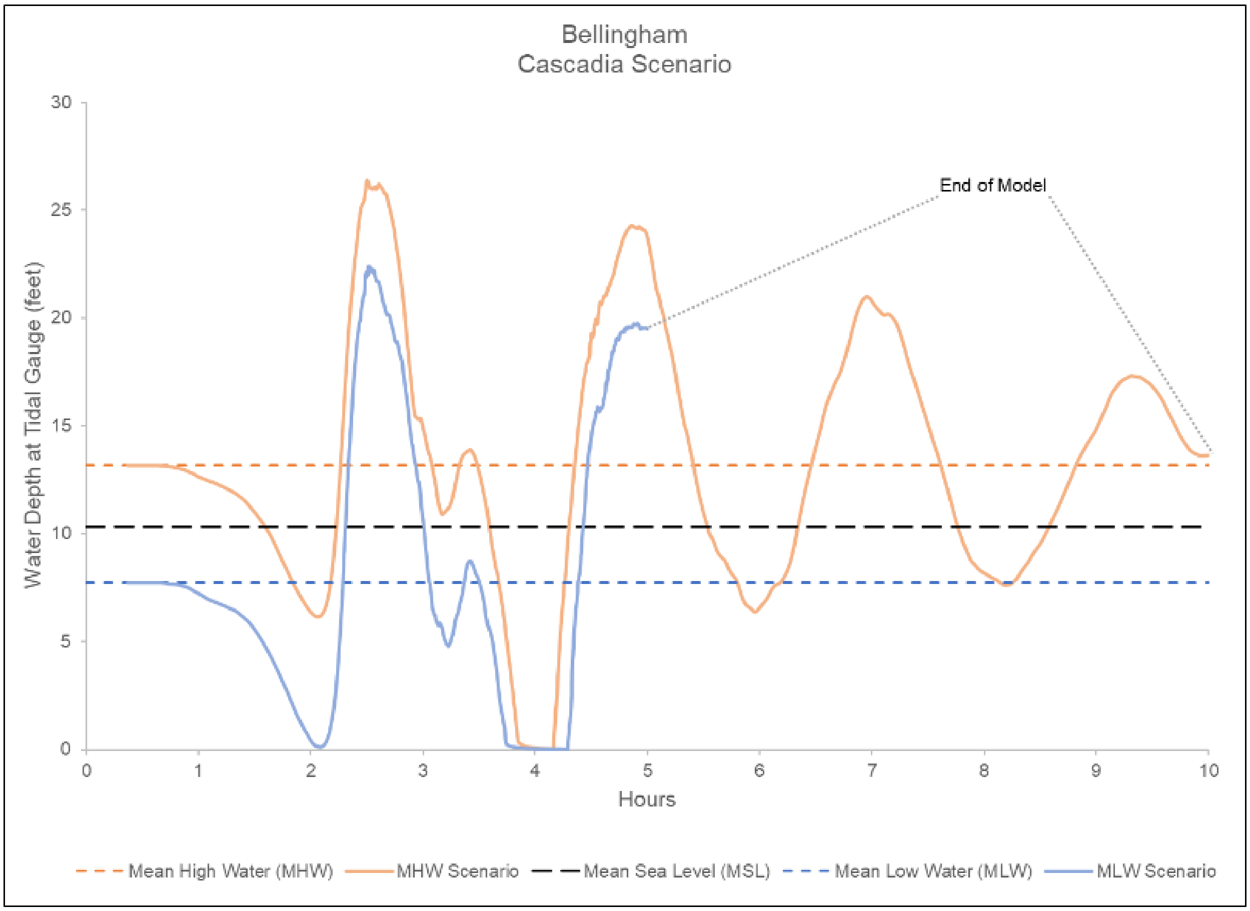


Figure 14: A comparison of water depths for a tsunami simulated by the Cascadia subduction zone (CSZ) L1 scenario modeled at Mean High Water (MHW) and the Mean Low Water (MLW) tidal datums. Water depth values were recorded at a simulated tide gauge location in the Bellingham study area shown in Figure 15 as "simulated tide gauge". Tsunami wave amplitudes deviate from the MHW and MLW tidal datums, respectively.

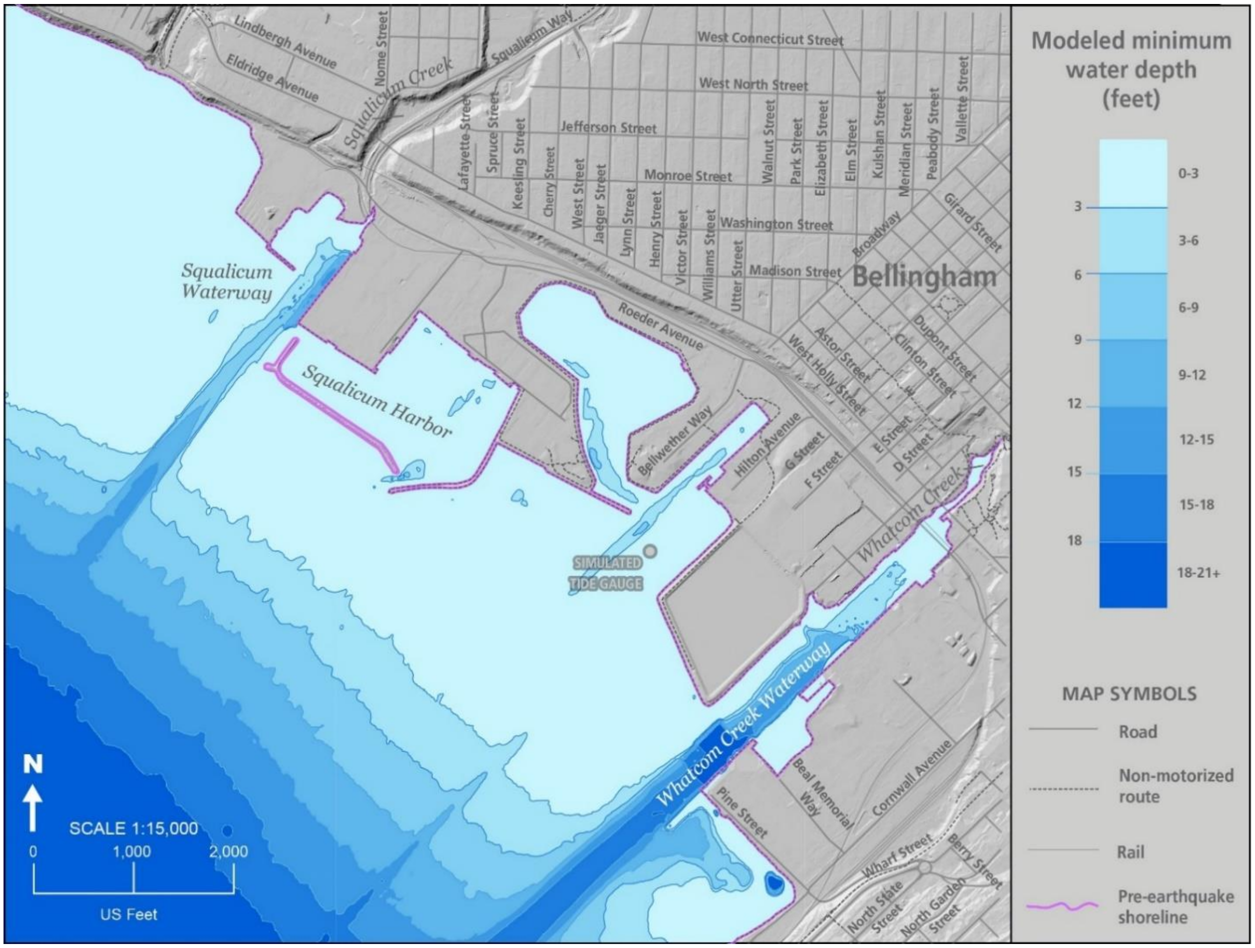


Figure 15: Modeled minimum water depth from a tsunami generated by the Cascadia subduction zone (CSZ) L1 scenario in Bellingham. Each colored zone has a 3-foot water depth interval. In the zone closest to land, water depth drops to 3 feet or less. Refer to the designated tide gauge plots to see the relative timing of each wave drawdown.

At the Bellingham Cruise Terminal location in Fairhaven drawdown will also occur but is not expected to be quite as drastic as at the waterfront properties in Bellingham due to the depth of the sea floor just offshore.

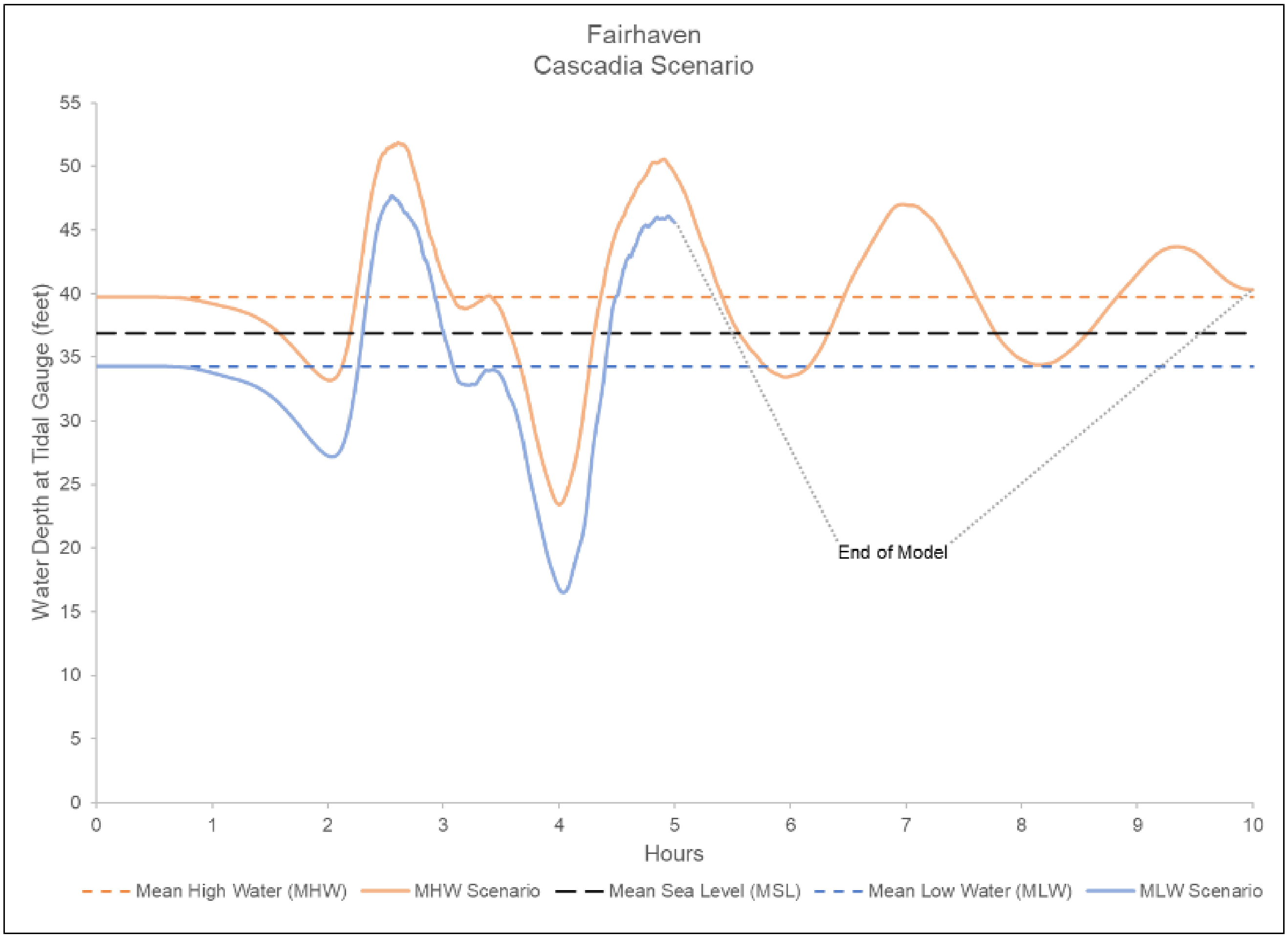


Figure 16: A comparison of water depths for a tsunami simulated by the Cascadia subduction zone (CSZ) L1 scenario modeled at Mean High Water (MHW) and the Mean Low Water (MLW) tidal datums. Water depth values were recorded at a simulated tide gauge location in the Bellingham study area shown in Figure 17 as "simulated tide gauge". Tsunami wave amplitudes deviate from the MHW and MLW tidal datums, respectively.

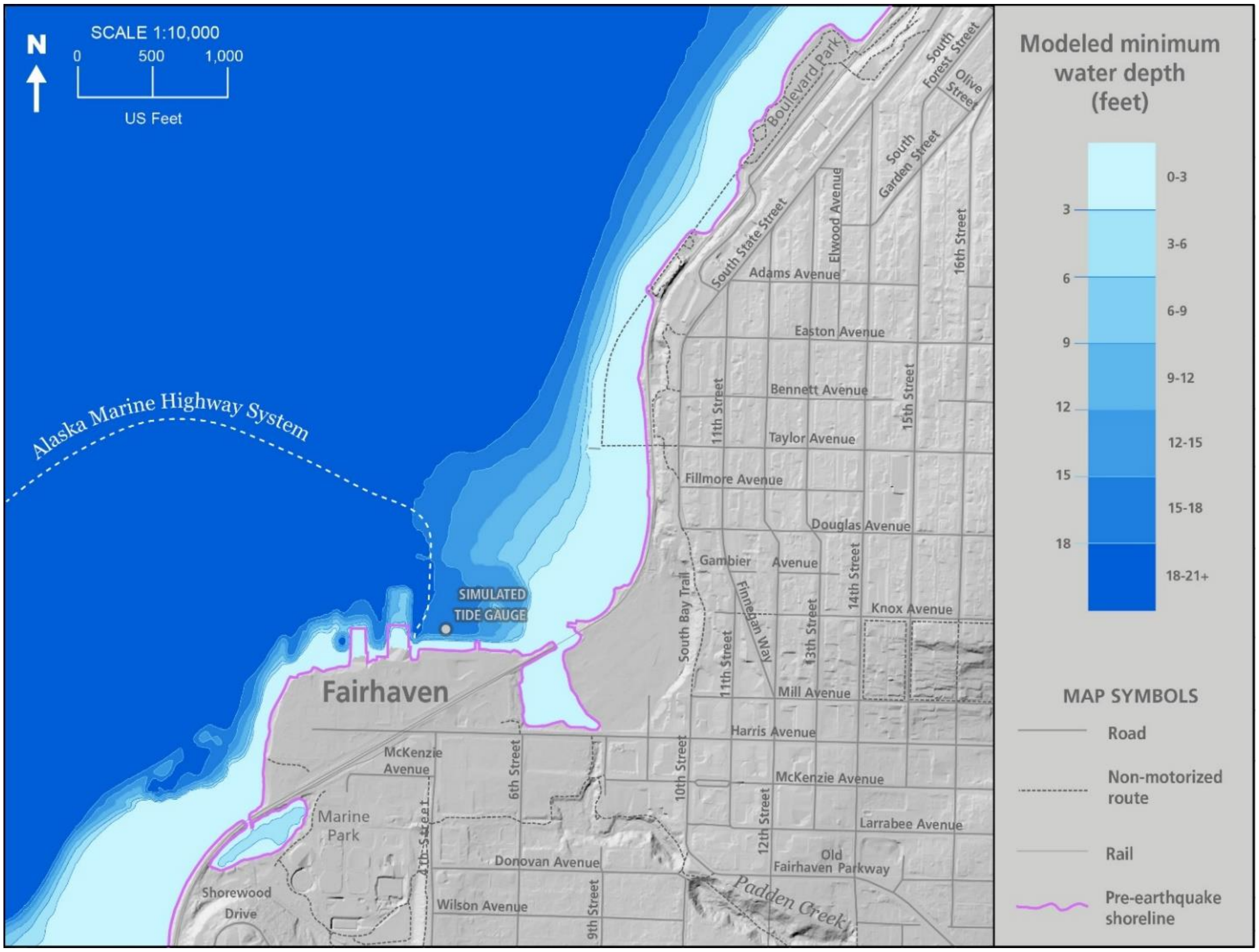


Figure 17: Modeled minimum water depth from a tsunami generated by the Cascadia subduction zone (CSZ) L1 scenario in Fairhaven. Each colored zone has a 3-foot water depth interval. In the zone closest to land, water depth drops to 3 feet or less. Refer to the designated tide gauge plots to see the relative timing of each wave drawdown.

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

Damage occurring from tsunamis inside harbors can be directly attributed to strong currents. These tsunami driven currents are in excess of existing or 'normal' currents in the area, meaning their speed is applied on top of the base current speed. Damage can vary based on the age and location of docks and boats yet some generalities about the relationship between tsunami currents and damage can be noted.

One such generality is a trend of damage increasing with increased current speed. There is a noticeable threshold for damage initiation at ~ 3 knots (1 knot = 1.15 miles per hour). At over 6 knots damage transitions from moderate to major, and as currents reach over 9 knots damage levels move into extreme damage categories.

Currents = Damage

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

It should be noted that more recent data indicate that although the 3-6-9 knot thresholds work for newer (<30-40 years old) and well-maintained docks and harbor infrastructure, velocity thresholds of 2-5-7 knots might be more appropriate damage thresholds for older (>40-50 years old) and less maintained docks.

Damage Index	Damage Type
0	No Damage
1	Small buoys moved
2	Docks/small boats damaged, Large buoys moved
3	Moderate dock/boat damage, Mid-sized vessels off moorings
4	Major dock/boat damage, large vessels off moorings
5	Complete destruction

Table 1: current velocity and associated damage

The Squalicum Harbor area is anticipated to experience damaging currents during a local tsunami event. These strong and unpredictable currents are modeled to be 0-3 knots in excess of normal current speeds throughout the majority of Bellingham Bay. However, inside the confined harbors and outside of the harbor entrances currents can be expected to be much faster, at least 3-6 knots and potentially up to 6-9 knots. Excess currents between 6 and 9 knots that are expected here have the potential to cause moderate to major damage to vessels and docks and could pull mid-sized vessels free from moorings. The fastest tsunami currents near Squalicum Harbor are anticipated to be just shore side of the narrow entrances to the harbor basins, with currents here exceeding 9 knots. Currents over 9 knots are considered to cause major damage or complete destruction of vessels or infrastructure and could pull even large vessels off their moorings and set them adrift.

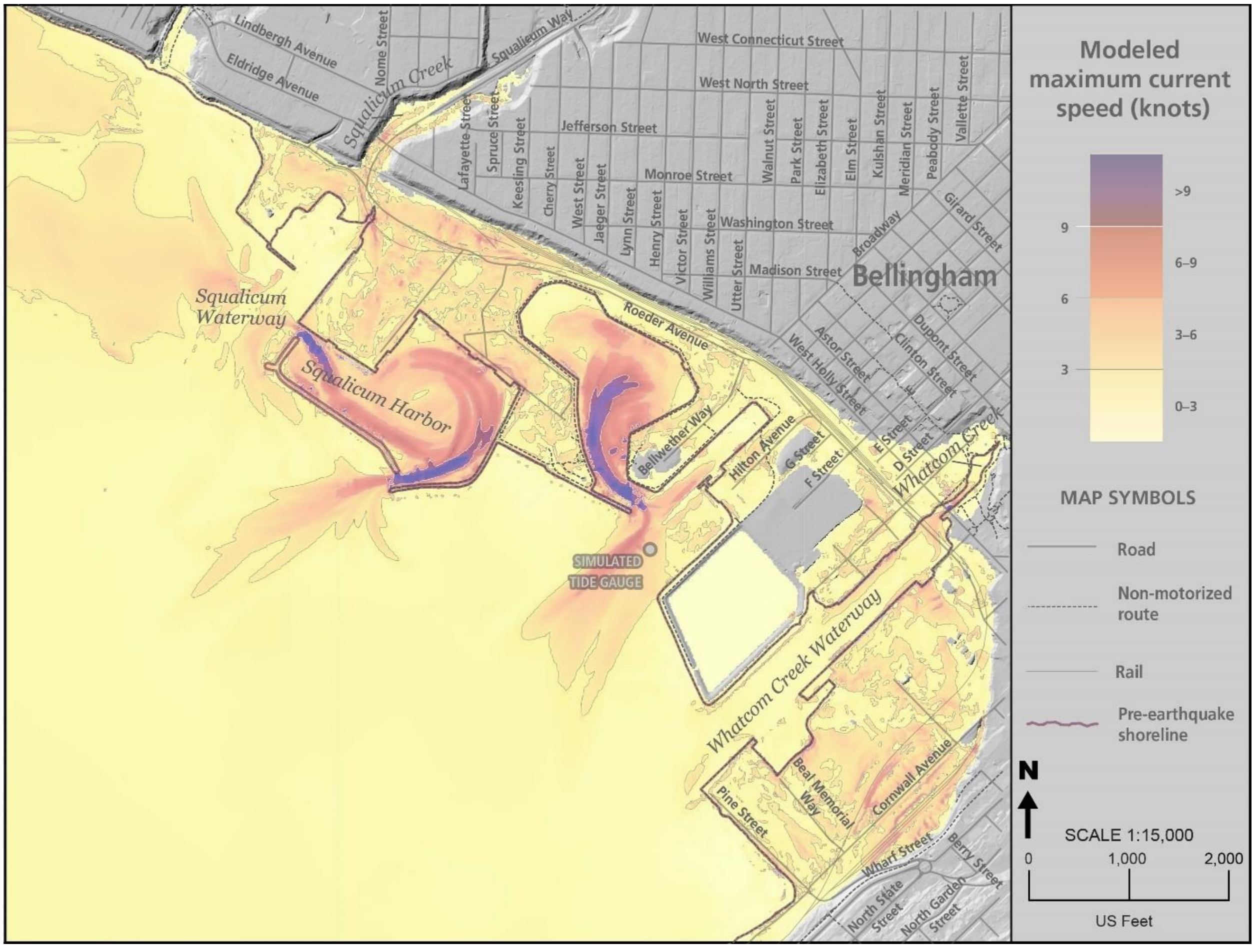


Figure 18: Modeled current velocity from a tsunami generated by the Cascadia Subduction Zone (CSZ) L1 scenario in Bellingham.

At the Bellingham Cruise Terminal area, like the majority of Bellingham Bay, the excess currents are anticipated to be around 0-3 knots in most areas, with the exception being the mouth of Padden Creek and open water to the southwest of the terminal area. Here the currents rounding the point are expected to be up to 6 knots. While this is mostly open water with little infrastructure around, the area would still be dangerous to any boaters on the open water during the event.

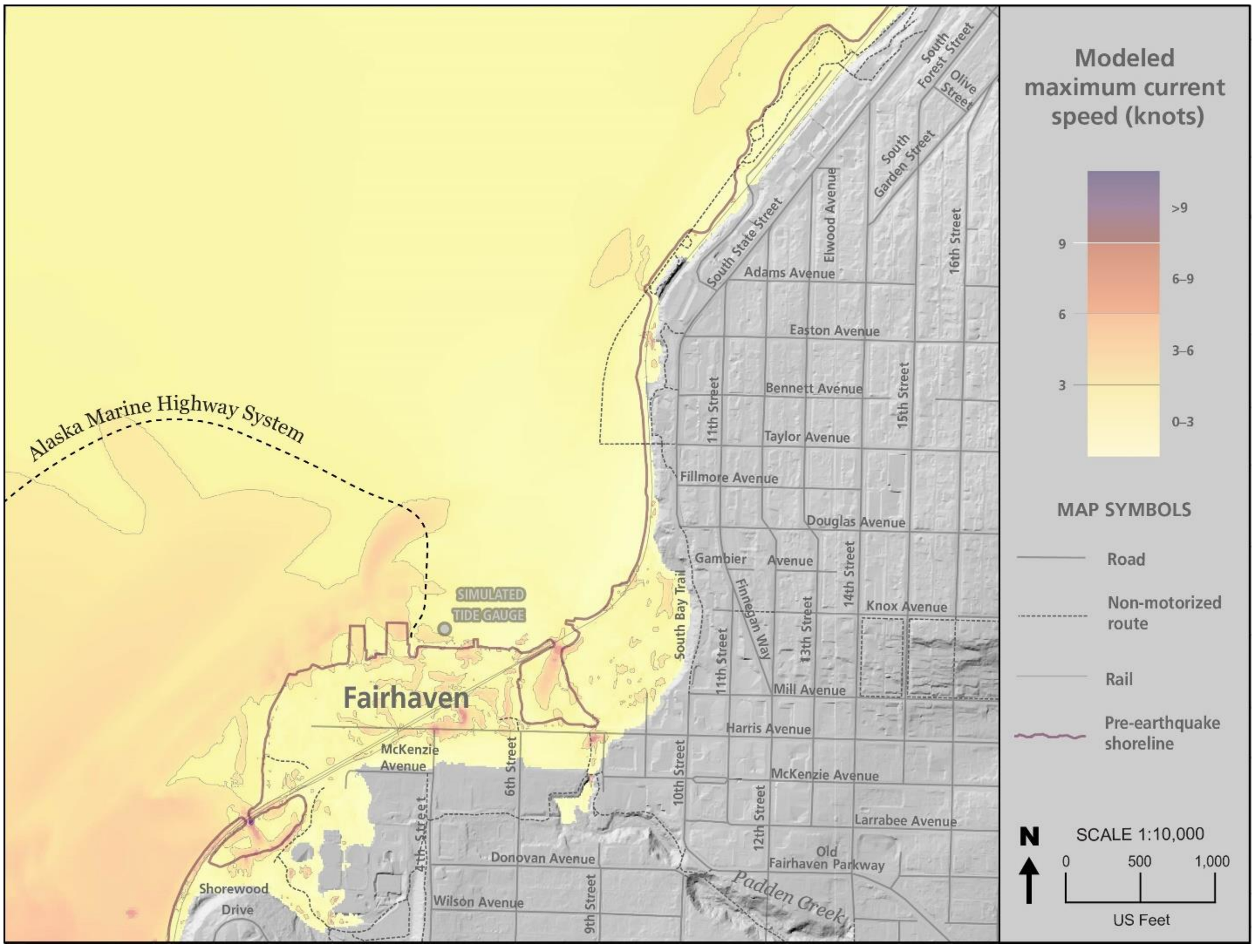


Figure 19: Modeled current velocity from a tsunami generated by the Cascadia subduction zone (CSZ) L1 scenario in Fairhaven.

Actionable Natural Warning Signs

The earthquake itself is the warning for a local tsunami. There may not be enough time to receive an official tsunami warning. Be alert for the earthquake and other tsunami natural warning signs:

- **Onshore**
    - Strong and/or long ground shaking
    - Loud roar from 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
    - You may see a rapid or extreme shift in currents and simultaneous changes in wind wave heights

General Guidance on Response to Natural Warning Signs or Official Warnings

Because you may have only minutes to take action 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 having at least 3 days of food, fuel, and water stored on your vessel.

<table>
<tr>
<td>Tsunami Warning or Natural Warning Signs</td>
<td>During the event

• If you are on land or tied up at the dock:
o Leave your vessel and head for high ground or inland 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:
o 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.
o 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.
o However, if you can safely beach or dock your vessel and evacuate to high ground before the tsunami arrives, this is</td>
</tr>
</table>

Tsunami Warning or Natural Warning Signs

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:**
  - **At less than 100 fathoms (600 ft):** Stop fishing operations immediately, freeing the vessel from any bottom attachments (cut lines if necessary). If you can beach or dock your vessel within 10 minutes of a natural warning and evacuate on foot to high ground, this is your best option. If that is not possible, head to water that is deeper than 100 fathoms, keeping in mind the following:
    - Proceed as perpendicular to the shore as possible
    - Sail directly into wind waves, keeping in mind that wind waves opposed by tsunami currents will be greatly amplified
    - Maintain as much separation as possible from other vessels
    - Synchronize movements with any other vessels to avoid collisions
  - **At 100 fathoms (600ft) or deeper:** If you are already at a location where the water depth is 100 fathoms or deeper, you are relatively safe from tsunamis.

After the event

- If you are in an offshore staging area, check with the United States Coast Guard (USCG) for guidance before leaving the staging area; conserve fuel by drifting until you know what actions you need to take.
- 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 usually the largest for tsunamis. At Kodiak, Alaska during the 1964 tsunami the first wave was 3.4 m (11 ft) at the 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 and to high ground out of the tsunami inundation zone was the only possible action.

Guidance for Distant Source Tsunamis

Maritime guidance in this section is based on anticipated effects of the maximum considered distant Alaska tsunami event. Other distant source tsunamis may also occur but are likely to cause less damage than the maximum considered scenario.

A distant source tsunami event will allow some time for local agencies and citizens to take steps to mitigate or reduce expected impacts of tsunami surges. The most important step is to evacuate from the tsunami evacuation zone prior to the expected arrival time of the first tsunami surge. However, there may not be enough time to accomplish all needed response actions before the first wave arrives. Local response activities could be extensive and may involve large numbers of people, resulting in congestion and delayed actions. Therefore, the actions to be taken must be prioritized and based on life-safety preservation. Only those actions assured to be successful should be attempted.

Distant Source Tsunami Risk for the Port of Bellingham

A tsunami event generated from a distant earthquake, while being less dangerous than a locally generated event, will still bring significant impacts to the Port of Bellingham properties located on Bellingham Bay, including:

- Significant water level changes
- Potential for inundation of dry land
- Significant drawdown of water levels with the potential to expose the sea floor in shallow areas
- Strong and unexpected currents
- The first wave may not be the largest or most dangerous

In order to prepare for a distantly generated tsunami event, an Alaska-Aleutian Subduction Zone (AASZ) megathrust earthquake with moment magnitude of 9.24 (called AKMaxWA) was simulated and modeled for its impacts. This simulated event is similar to the 1964 Alaska earthquake (M_w 9.2). This model produces very large waves along the AASZ. The wave travels across the Pacific Ocean to Washington and propagates into the Strait of Juan de Fuca, Puget Sound, and the Strait of Georgia. The wave crests reach the Bellingham waterfront at approximately 6 hours following the earthquake. With this model there is no drawdown before the first wave arrives, although there is drawdown after the first wave. In this simulation the second wave is higher than the first.

Anticipated Water Level Changes from a Distant Alaska Tsunami Event

Modeling of an AKMaxWA earthquake-generated tsunami indicates that significant portions of Squalicum Harbor, Bellingham Shipping Terminal, and surrounding areas may be inundated by water. The flow depth of the inundation on land ranges from slightly more than a foot to depths potentially in excess of 6 feet in some locations.

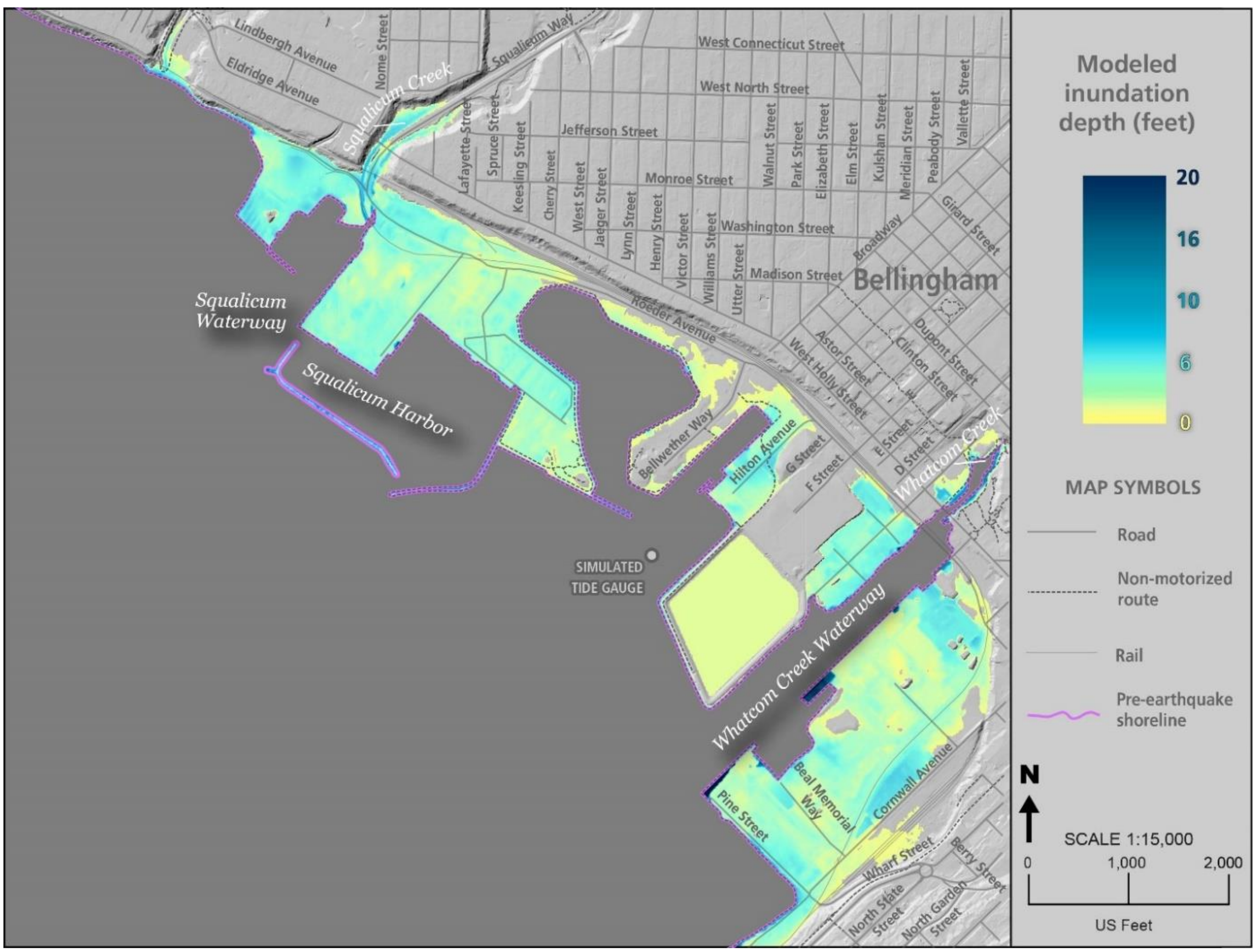


Figure 20: Modeled inundation depth from a tsunami generated by the Alaska-Aleutian subduction zone (AASZ) AKMaxWA scenario in Bellingham.

At the Bellingham Cruise Terminal location some inundation is expected throughout the terminal area. The flow depth is anticipated to exceed 10 feet at the Alaskan Marine Highway System docks and other docks nearby. The surrounding land up to Harris Ave has potential to be flooded at a depth of over 1 foot or more.

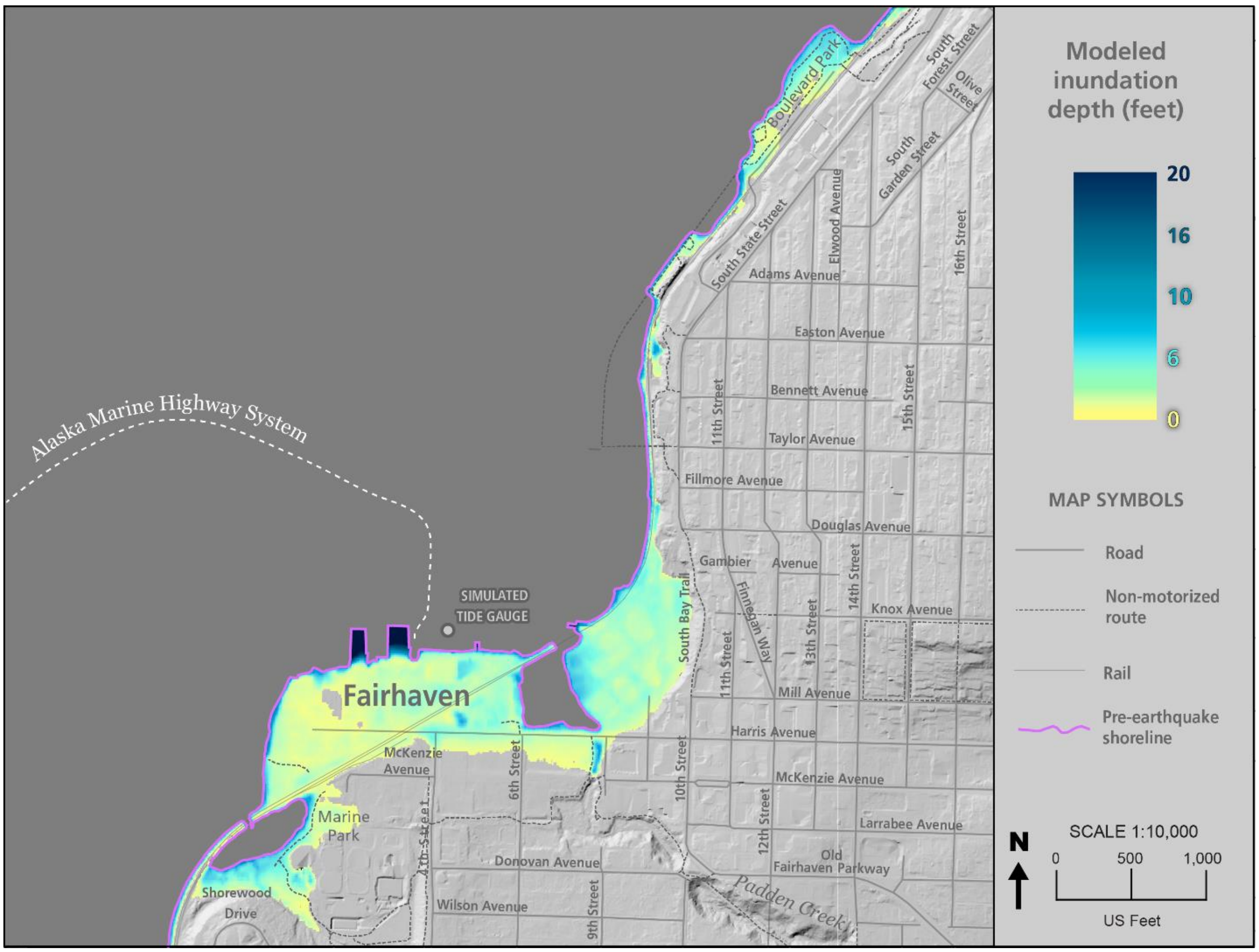


Figure 21: Modeled inundation depth from a tsunami generated by the Alaska-Aleutian subduction zone (AASZ) AKMaxWA scenario in Fairhaven.

Water Level Drawdown Leading to Potential Exposure of Sea Floor

A simulation of the Alaskan event anticipates multiple drastic drawdowns of water during the event, the severity of which will be affected by the tide stage at the time. At Squalicum Harbor and the Bellingham Shipping Terminal areas the simulation shows that the minimum water depth that remains due to the drawdown depends heavily on the tide stage. At mean high tide the first major drawdown will cause the water level to quickly drop below the level of mean low water but will not cause extensive exposure of the sea floor. If the first (and possibly the second) major drawdown occurring at around 7 hours after the start of the event coincides with low tide it will likely expose the sea floor in the shallower areas for a significant amount of time. This means some vessels in the Squalicum Harbor area could become grounded and left resting on the floor of the sea. The following minimum water level maps are modeled based on Mean Low Water, meaning that the time of minimum water depth coincides with the mean lowest tide. This provides the most conservative estimate of the minimum level of water remaining in the study area.

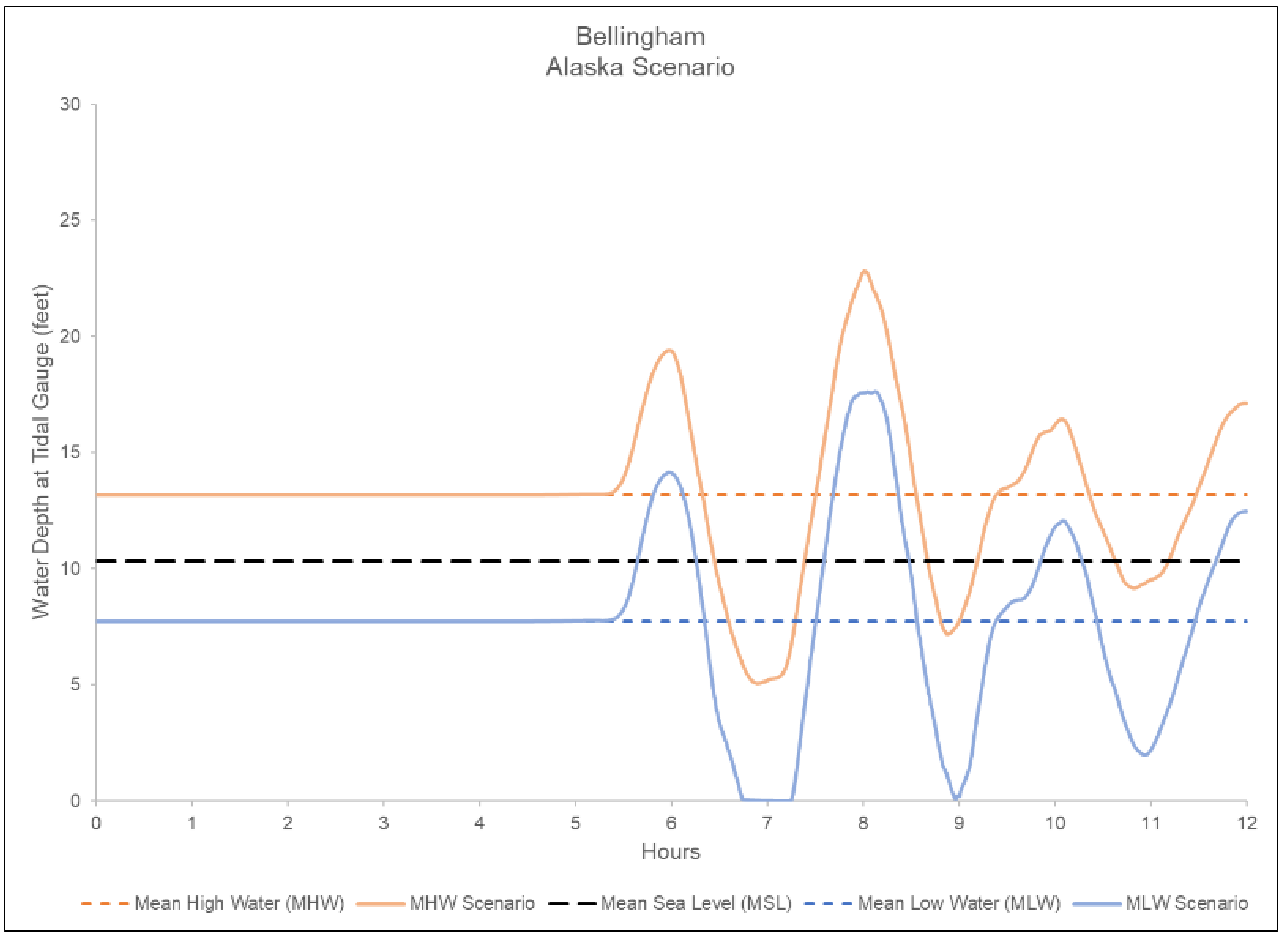


Figure 22: A comparison of water depths for a tsunami simulated by the Alaska-Aleutian subduction zone (AASZ) AKMaxWA scenario modeled at Mean High Water (MHW) and the Mean Low Water (MLW) tidal datums. Water depth values were recorded at a simulated tide gauge location in the Bellingham study area shown in Figure 23 as "simulated tide gauge". Tsunami wave amplitudes deviate from the MHW and MLW tidal datums, respectively.

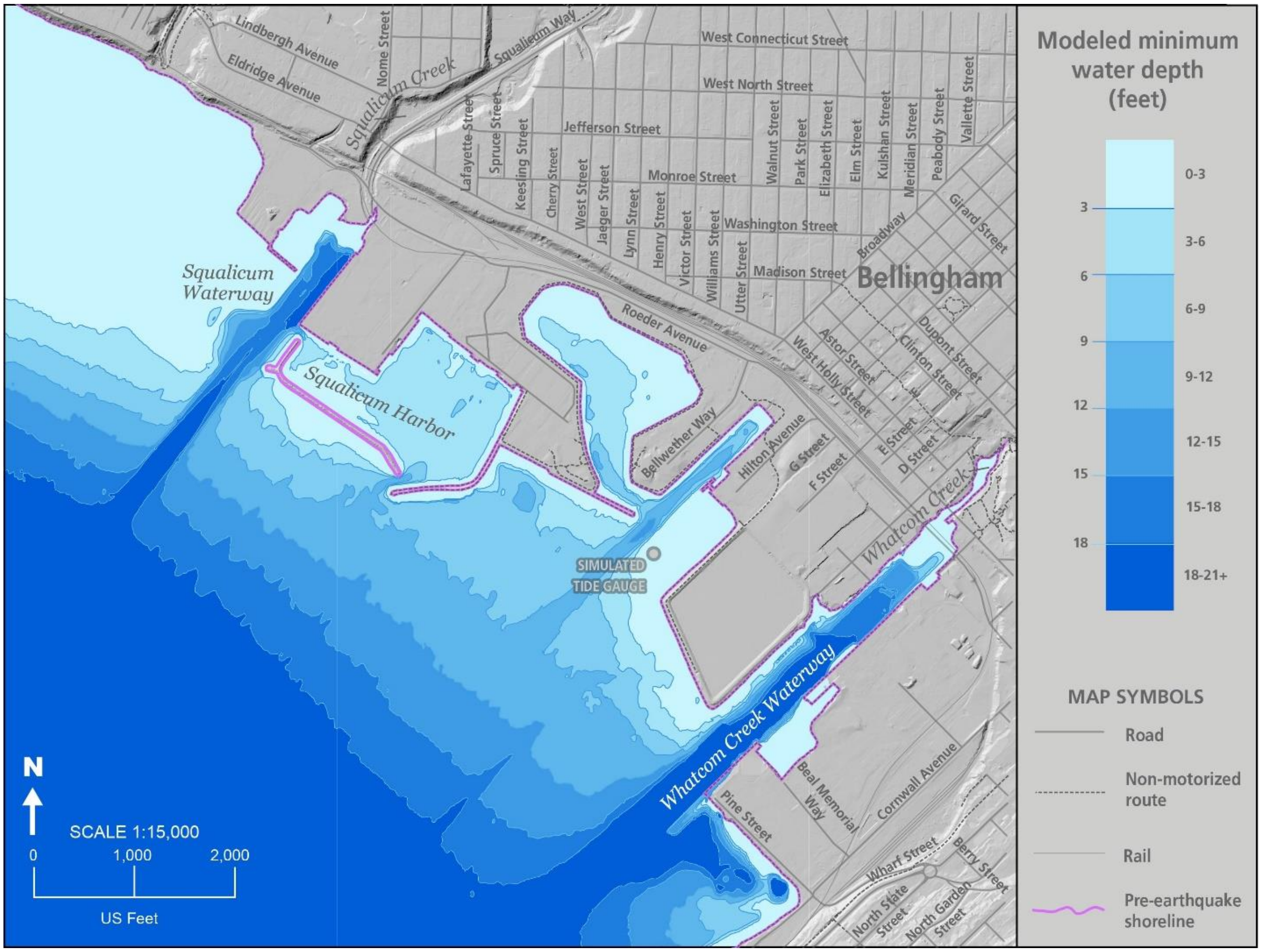


Figure 23: Modeled minimum water depth from a tsunami generated by the Alaska-Aleutian subduction zone (AASZ) AKMaxWA in Bellingham. Each colored zone has a 3-foot water depth interval. In the zone closest to land, water depth drops to 3 feet or less. Refer to the designated tide gauge plots to see the relative timing of each wave drawdown.

At the Bellingham Cruise Terminal location drawdown will also occur but is not expected to lead to minimum water levels that are quite as drastic as at the Port of Bellingham location due to the depth of the sea floor just offshore. Any areas where the sea floor is potentially exposed will be very near to the shoreline.

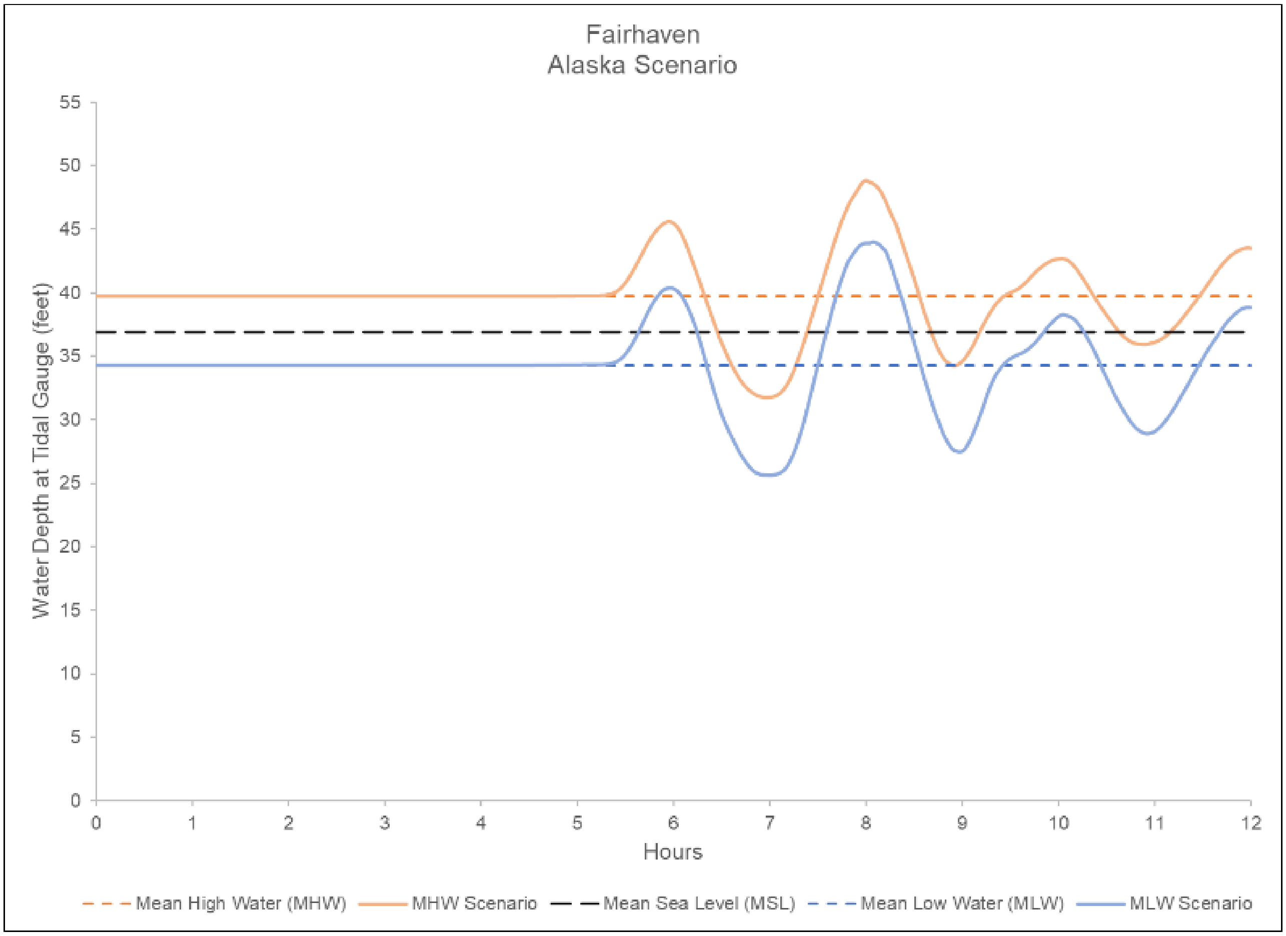


Figure 24: A comparison of water depths for a tsunami simulated by the Alaska-Aleutian subduction zone (AASZ) AKMaxWA scenario modeled at Mean High Water (MHW) and the Mean Low Water (MLW) tidal datums. Water depth values were recorded at a simulated tide gauge location in the Fairhaven study area shown in Figure 25 as "simulated tide gauge". Tsunami wave amplitudes deviate from the MHW and MLW tidal datums, respectively.

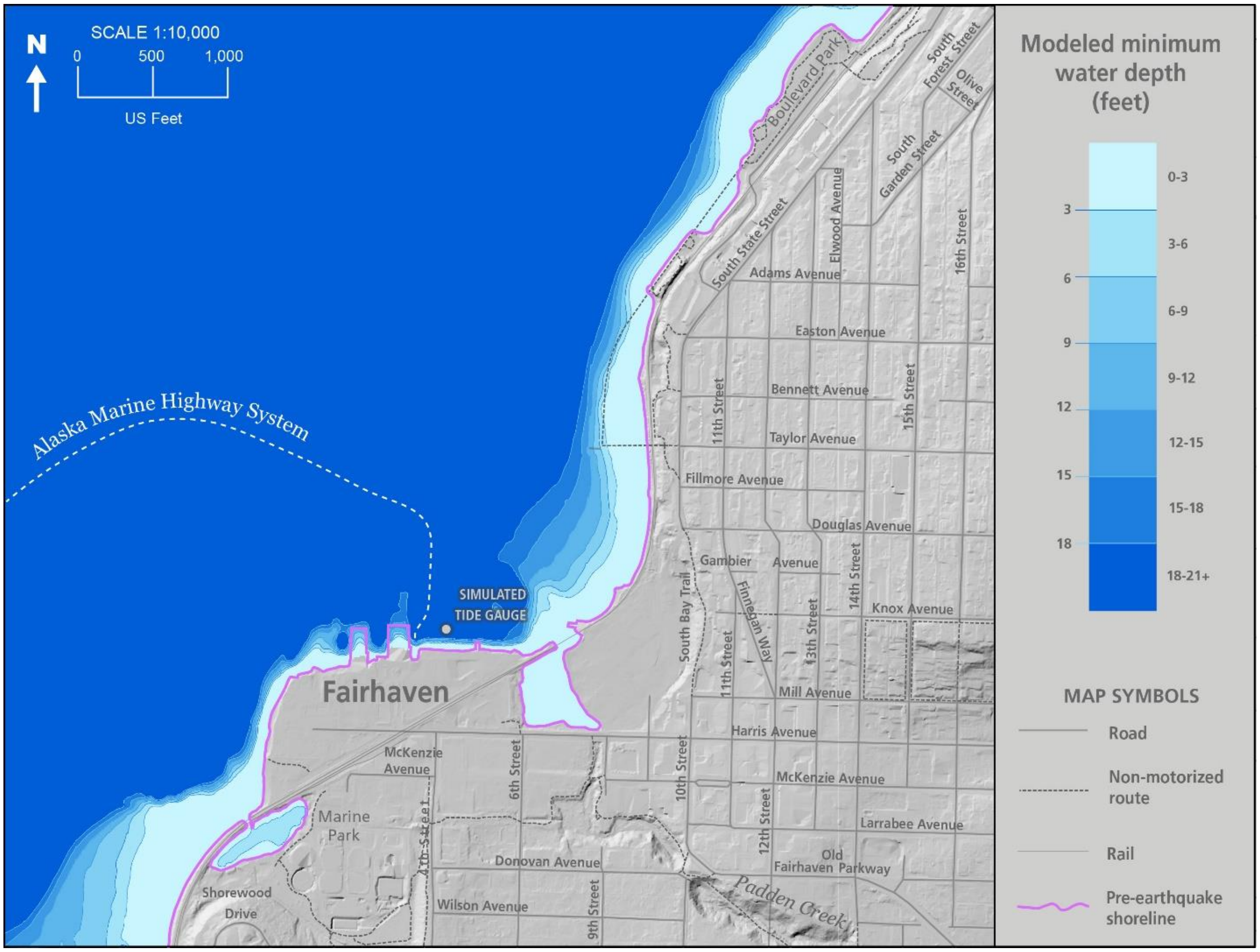


Figure 25: Modeled minimum water depth from a tsunami generated by the Alaska-Aleutian subduction zone (AASZ) AKMaxWA in Fairhaven. Each colored zone has a 3-foot water depth interval. In the zone closest to land, water depth drops to 3 feet or less. Refer to the designated tide gauge plots to see the relative timing of each wave drawdown.

Current Velocity, Areas of Dangerous and Unpredictable Currents

The Squalicum Harbor area is anticipated to experience potentially dangerous currents during a distant tsunami event originating in Alaska. These strong and unpredictable currents are anticipated to be on the lower end of the 0-3 knot range (1 knot = 1.15 miles per hour) throughout the majority of Bellingham Bay. Keep in mind, these tsunami driven currents are in excess of any existing or 'normal' currents in the area. During a distant event, the strongest currents are expected to be confined to just inside the harbor entrances. In the Outer harbor basin both the west and south harbor entrances have the potential to experience currents in the 3-6 knot range. While currents in this range will most likely not cause significant damage, travel though this area will be dangerous. The east harbor entrance of the Inner harbor basin has potential for stronger currents inside the entrance, possibly extending into the 6-9 knot range in places. Travel though this area could be highly dangerous, and any infrastructure in those areas could sustain damage.

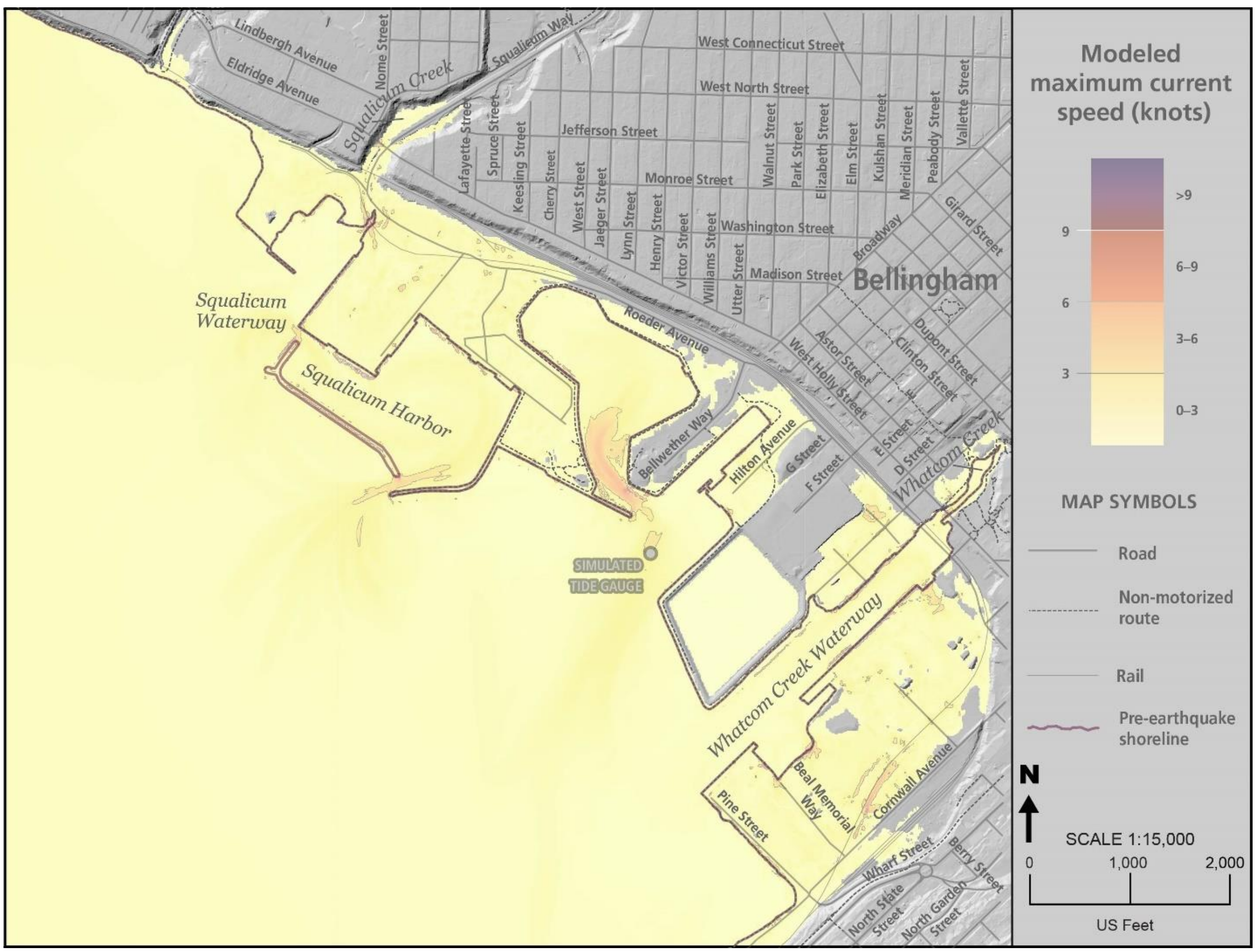


Figure 26: Modeled current velocity from a tsunami generated by the Alaska-Aleutian subduction zone (AASZ) AKMaxWA in Bellingham.

At the Bellingham Cruise Terminal area, like the majority of Bellingham Bay, the excess currents are anticipated to be at the lower end of the 0-3 knot range in most areas. While this poses little danger to the nearby infrastructure, the excess currents in the area could still be dangerous to any inexperienced boaters on the open water during the event.

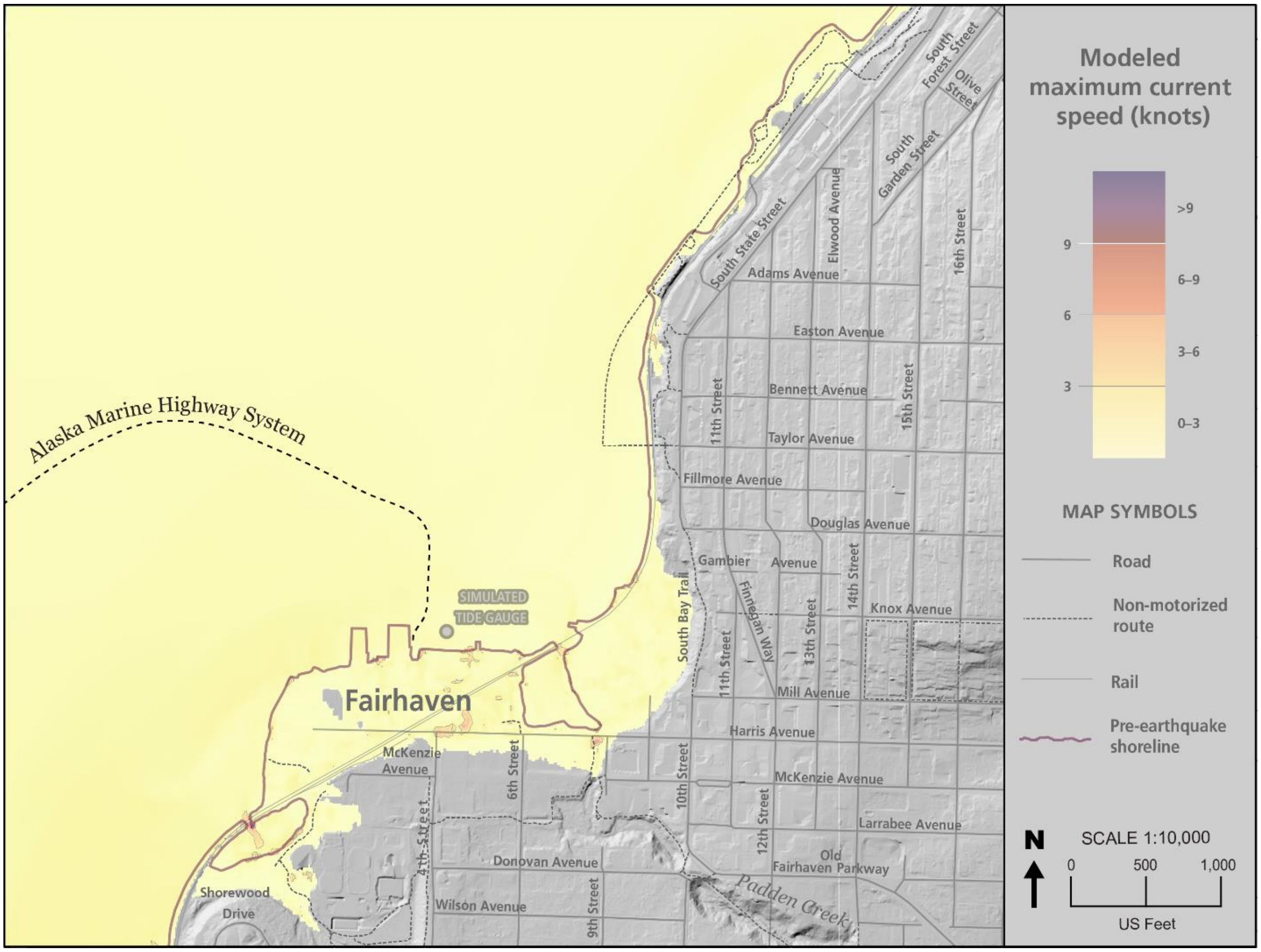


Figure 27: Modeled current velocity from a tsunami generated by the Alaska-Aleutian subduction zone (AASZ) AKMaxWA in Fairhaven.

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

Prior to the arrival of the March 11, 2011 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.

Actionable Natural Warning Signs

For a distant source tsunami, you will not feel shaking and there is a possibility that you may not receive an official 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:

- **Onshore**
  - Loud roar from ocean
  - Water rapidly receding, possibly exposing the sea floor
  - Wall of water surging towards shore faster than any tide
- **Offshore**
  - You could see a rapid or extreme shift in currents and simultaneous changes in wind wave heights

General Guidance on Response to Tsunami Advisories and Warnings for a Distant Event

<table>
<tr>
<td>Tsunami Advisories</td>
<td>During the event

• 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.

After the event

• Port authorities will not allow public to reenter structures and vessels in the water until Advisory is cancelled and conditions are safe.</td>
</tr>
<tr>
<td>Tsunami Warnings</td>
<td>During the event

• 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 to injury. However, if they do decide to go offshore, they should proceed to a staging area greater than 30 fathoms (180 ft) & at least 1/2 mile from shore and have the experience, fuel, and supplies to stay offshore for more than 24 hours or possibly have</td>
</tr>
</table>

Tsunami Warnings

    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 high ground or inland.**
  - **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.**
    - **PLEASE REMEMBER:** There may be road congestion. There may also be vessel congestion in the harbor as ships, barges, and other vessels attempt to depart at the same time. All vessels should monitor VHF Channel 16 and use extreme caution. NEVER impede another vessel.
  - **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 event; then exit the tsunami inundation zone.

After the event

- The "CAUTIONARY RE-ENTRY" DOES NOT MEAN THAT THE HARBOR IS OPEN. The "CAUTIONARY RE-ENTRY" message is for land entry only.
- Mariners at sea should 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.

Tsunami Alerting

Tsunami alerts for Washington are originated by the National Oceanic and Atmospheric Administration's (NOAA) National Tsunami Warning Center (NTWC) in Palmer, Alaska. The Center detects, locates, sizes, and analyzes earthquakes throughout the world 24 hours a day. When an earthquake occurs with the potential to generate a tsunami the NTWC will evaluate the event based on set parameters and determine the level of alert necessary for the event. The NTWC will then use data from deep ocean tsunami detectors to judge the size, speed and severity of the event and alter the alert levels as appropriate. Once the NTWC issues an alert, that information is sent to the appropriate federal and state authorities to be disseminated to the public. In the event of a warning the National Weather Service will send an alert through NOAA Weather Radios in the affected area. The Washington State Emergency Operations Center (SEOC) will activate the tsunami All Hazards Alert Broadcast (AHAB) sirens. Bellingham currently has two sirens. One is located in Squalicum Harbor by Gate 5 and the other in Fairhaven at the entrance to the Bellingham Cruise Terminal. The SEOC will also send an alert though the wireless emergency alert system (cell phone alerts), as well as through the Emergency Alert System (broadcast alerts on television and radio). The Whatcom County Sheriff's Office Division of Emergency Management will also issue alerts as described in the Whatcom County Tsunami

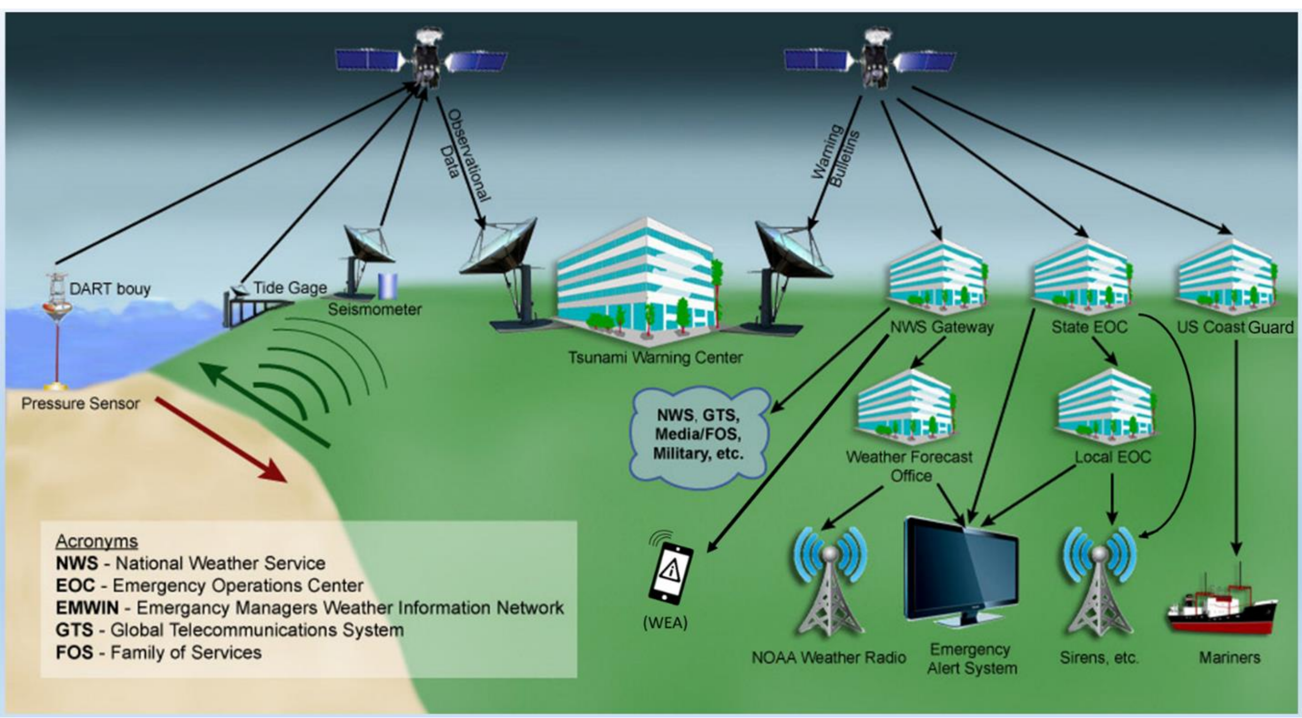


Figure 28: Diagram of tsunami alert dissemination

Action Plan, in cooperation with the SEOC.

These types of alerts are most important for distant events and can also be useful for those further from the source of a local event. For those individuals near the source, such as people on the outer coast for a CSZ event, 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.

Determining Whether a Tsunami Could Be Generated

In most cases the first sign of a potential tsunami is an earthquake. Seismic waves travel about 100 times faster than tsunamis, so information about an earthquake is available before information about any tsunami it may have generated. Three key pieces of information about an earthquake help the tsunami warning centers determine if it was tsunamigenic (capable of generating a tsunami): location, depth, and magnitude. The warning centers use this preliminary seismic information to decide if they should issue a tsunami message and at what alert level(s).

Once a message is issued, the warning centers conduct additional seismic analysis and run tsunami forecast models using information from the seismic and water-level networks as it becomes available. These numerical models use the real-time information and pre-established scenarios developed from historical tsunami information to simulate tsunami movement across the ocean and estimate coastal impacts, including wave height and arrival times, the location and extent of coastal flooding, and event duration. The resulting forecasts help the warning centers decide if they should issue an updated alert or cancellation message.

Tsunami Alert Messages

The National Tsunami Warning Center (NTWC) issues tsunami Warnings, Advisories, Watches, and Information Statements. Each has a distinct meaning relating to local emergency response. In summary:

Warning	→	**Inundating wave possible**	→	**Full Evacuation Suggested**
Advisory	→	**Strong currents likely**	→	**Stay away from the shore**
Watch	→	**Danger level not yet known**	→	**Get ready to take action**
Information	→	**Minor waves at most**	→	**No action suggested**

Table 2: Official tsunami alerts, associated effects, and protective actions to be taken.

Based on seismic data analysis or forecasted amplitude (dependent on whether the Center has obtained sea level data), NTWC will issue the appropriate message. Warnings and advisories suggest that action be taken. Watches are issued to prompt people to get ready to take action. Information Statements are issued to let people know that there was a large earthquake, but there is little to no danger. Once the danger level is determined, the watch is upgraded to a warning or advisory, or canceled. 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 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.

- **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. Watches are normally issued based on seismic information without confirmation that a destructive tsunami is underway.

- **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 Alerts

Those in the maritime community should be aware of both the types of alerts issued, and the actions they could need to take when an alert is received. All of those in the maritime community should be equipped with a way to receive official alerts through as many means as possible. Cell phone, text and internet-based alerts may be able to be received in locations near shore, in port, and other areas normal communications work properly. Boaters at sea or in locations where reliable cell phone signals and internet access is limited or nonexistent will need to have alternate forms of receiving emergency alerts such as a marine radio, a NOAA weather radio or both.

Tsunami alerts can be received by officials and the public in several ways which are outlined in the appendices, along with a more detailed look into alerting dissemination responsibilities. In Whatcom County, The Whatcom County Sheriff's Office Division of Emergency Management will issue alerts as described in the Whatcom County Tsunami Action Plan, in cooperation with the SEOC. The Whatcom County Tsunami Action Plan contains both the methods and sample texts for the messages that will be disseminated. 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. Vessel captains and boat owners/operators should ensure their vessel is equipped with a marine radio that will receive emergency alerts, and ensure they have an alternate method to receive alerts that will work on the water such as a NOAA weather radio.

Actionable Tsunami Alert Levels

Tsunami warnings and advisories are the two actionable alert levels for maritime communities. For both advisory and warning level events, it is important that clear and consistent directions are provided to the entire boating community and to waterfront businesses.

Sign up to receive notifications from the National Tsunami Warning Center in Palmer, Alaska at the following website: https://ntwc.ncep.noaa.gov/?page=productRetrieval. The Center issues two types of bulletins that require action by the Washington maritime community:

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

Table 3: Actionable tsunami alert levels and associated effects.

Section 2: Response Guidance for the Port of Bellingham

Response actions taken in the initial minutes and hours of an emergency are critical for protecting lives and property. Some examples include evacuating people to high ground and restricting people from entering the tsunami inundation zone. It is important to understand which actions are recommended and who is responsible for taking them. Most of the response actions that are discussed are suitable for the Port of Bellingham's properties on Bellingham Bay. Some actions will need to be evaluated and a couple of actions are not recommended, such as moving vessels out of the harbor.

Response Measures	Suitable for Port of Bellingham
Shut down infrastructure before tsunami waves arrive	Yes
Evacuate public/vehicles from waterfront areas	Yes
Restrict boats from moving during the tsunami	Yes
Prevent ships from entering harbor during the tsunami	Yes
Secure boat/ship moorings	Yes
Personal floatation devices for port staff	Yes
Stage emergency equipment outside affected area	Yes
Activate mutual aid system as necessary	Yes
Activate incident command at evacuation sites	Yes
Alert key First Responders at a local level	Yes
Restrict traffic entering the Port, aid traffic evacuating	Yes
Identify personnel to assist rescue, survey, and salvage	Yes
Identify boat owners/individuals who live aboard vessels; establish phone tree or other notification process	Yes
Repositioning ships within the harbor – ONLY FOR DISTANT EVENT	Review
Remove small boats/assets from water	Review
Remove hazardous materials away from water	Review
Remove buoyant assets away from water	Review
Moving boats and ships out of harbor	No
Move large, deep keeled ships from harbor entrances	No

Table 4: Response measures and suitability for Port of Bellingham.

Response Measures for The Port of Bellingham

Shut Down Infrastructure Before Tsunami Arrives

Suitable for the Port of Bellingham: Yes

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 the event, leading to extensive environmental cleanup. Having a method and plan for how to quickly shut down infrastructure in the event of a tsunami can help to lessen or even eliminate that problem. Ensuring that there are shutoffs in appropriate locations that are easy to access and use is one way to help mitigate that issue. Automatic shutoffs designed to operate when lines are damaged, or even valves configured to operate upon receipt of an Earthquake Early Warning, is another.

The Port of Bellingham would need to evaluate what infrastructure has the highest risk, what measures that are currently available can be taken to quickly shut processes down, and what measures that are not currently available should be developed in order to fill any gaps.

Evacuate Public/Vehicles from Waterfront Areas

Suitable for the Port of Bellingham: Yes

Limiting the amount of people and vehicles that would be in the inundation area when dangerous tsunami waves arrive will help to 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 event.

The Port of Bellingham is a member of the Whatcom County Emergency Management Council Interlocal Agreement for the provision of Emergency Management Services as authorized under RCW 39.34 and 38.52. There are two applicable plans that are specific to any tsunami response – The Whatcom County Comprehensive Emergency Management Plan and the Whatcom County Tsunami Action Plan. These comprehensive plans include a detailed and well-designed plan to evacuate all people and as many vehicles as feasible from the inundation zone around the harbor area and the Bellingham Cruise Terminal if faced with a potential tsunami event. Given the amount of time before the arrival of dangerous waves from the two scenarios looked at here, it is reasonable to assume that a full-scale evacuation of the areas could be completed prior to the wave arrival.

Restrict Boats from Moving During Tsunami

Suitable for Port of Bellingham: Yes

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 reduces the danger to life safety and can help to limit casualties from the event.

At the Port of Bellingham, assuming a full evacuation is executed and followed by all persons in the area, the risk of boats moving around during a tsunami will be limited as there should be no people remaining in the area to attempt to move any vessels. However, this only helps with vessels that were in port at the time of the evacuation. Vessels that are at sea and attempting to return to the port may still be at risk. Ensuring that all captains using the harbor and port are aware of the dangers of a tsunami event and know to return long before the waves arrive and not to attempt a return during the event can also help limit the danger of boats moving around in the area at the time.

Prevent Ships from Entering the Harbor During Event

Suitable for Port of Bellingham: Yes

Since the narrow entrances of most harbors are where tsunami-caused currents can be strongest, ships should not be entering or leaving the harbor through these areas during a tsunami event. While boaters should be encouraged to return to the harbor if possible before tsunami waves arrive and the strong currents associated with them, 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 an event, and when currents are at their strongest may prove impossible to pass through at all. If a port or harbor has a method of preventing ships from traveling through the area, perhaps by way of a physical barrier or other means, it should be utilized during a tsunami event. If there is no method of physical restriction another option would be through a combination of public education and some type of visual means. Flashing red lights, signage or similar means could be utilized to alert captains not to enter the harbor. Such visual means would need to be installed in advance and tested and maintained to ensure they are always in proper working order. Visual alerts of a closed entrance would need to be augmented with some type of education, such as on signage shoreside or instructions in harbor user agreements reviewed regularly to ensure that captains are aware of what the visuals indicate and know not to enter the harbor area when they are activated.

The entrances at Squalicum Harbor are not currently equipped with any type of barrier or mechanism to completely block or eliminate entry into the area. The logistical issues and cost of implementing such a barrier is most likely not worth the effort of installation. However, the port could consider other visual means of 'closing' the harbor entrances mentioned above, such as flashing lights, large readable signage, or even just sending by radio or other means a pre-scripted message of harbor closure during an event. As mentioned, this would need to be coupled with some education efforts aimed at captains and other users of the harbor so if used, captains would understand what the message means and know not to enter the harbor until informed it was safe to do so.

Secure Boat/Ship Moorings

Suitable for Port of Bellingham: Yes

During a distant source tsunami event most boats and ships will be safe inside the harbor if properly and securely moored. Prior to the initial wave arrival boat owners and/or harbor personnel can visually check that ships are properly and securely moored. Given the size of some harbors and number of slips and vessels to check it may not be possible, in the time available, to check the entire area and every vessel. Given this limitation the check should begin in the areas identified as at the most risk of strong currents and other hazardous conditions. Ideally vessel captains and owners would be encouraged to securely moor their vessels every time they dock, and a visual check could be conducted quickly. If owners and captains are vigilant about their mooring lines and security, then very few vessels would need to be additionally secured.

The Port of Bellingham could use the current velocity maps developed for this strategy to identify the most likely locations for dangerous currents and hazardous conditions in the harbor areas. Once the most dangerous areas are defined personnel could be identified who would conduct a mooring security check if a tsunami event were to occur. Given the time frame of around four hours after a distant tsunami is generated until the first waves arrive, a check of the most dangerous areas should be feasible by a handful of people. Additionally, if possible, personnel could conduct checks on a regular basis and Identify any vessels that are regularly moored in less than secure ways. Port personnel could then consider contacting those captains or owners, reminding them of the risks in having less than secure mooring lines and asking them to better secure their vessels. This would help to ensure very few vessels would need securing during an event.

Personal Floatation Devices/Vests for Port Staff

Suitable for Port of Bellingham: Yes

Ideally before the first dangerous waves were to arrive all public and port staff would have evacuated the area to high ground and thus be out of any danger. However, in the event of a close source local tsunami there may not be enough time to reach high ground. In such an event having floatation devices or vests easily available for port staff could help to reduce casualties. Any persons in the inundation zone when waves arrive are in extreme danger, and floatation devices will not guarantee safety. Even so, floatation devices at least offer those in danger a better chance of survival than persons without them.

The Port of Bellingham could consider the purchase of floatation devices for their staff and store them in easy to access locations for staff to use in an emergency. While such devices would not be a guarantee of safety, they would at least offer some protection for staff. The floatation devices would need to be placed in locations well known to staff where they are able to get to them quickly. Staff would also need to be educated on what the natural warning signs of a tsunami are so they would know to immediately don the floatation devices and then head for the safety of high ground. Hopefully, staff would reach high ground before the waves arrived, but if they were to get caught up in the waves the floatation devices would help keep them afloat if they were dragged out into the water.

Stage Emergency Equipment Outside Affected Area

Suitable for Port of Bellingham: Yes

The aftermath of a tsunami event will be chaotic, with widespread debris, buildings destroyed, hazardous materials spilled, and potentially even fires and casualties. This aftermath will require 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 moved out of the area before the waves arrive, so it is not damaged and remains operable for the post event response. Any necessary equipment should be identified in advance and a plan made to determine who will be responsible for how the equipment will be relocated away from danger. A staging area on high ground should be identified for the equipment until it is needed after the event.

Most of the emergency equipment that would respond to the Port of Bellingham after a tsunami event (fire trucks, ambulances, etc.) would be provided by the applicable Authority Having Jurisdiction, or as coordinated through the Whatcom County Unified Emergency Operations Center as specified in the Whatcom County Comprehensive Emergency Management Plan and the Whatcom County Tsunami Action Plan. This emergency equipment is normally staged in areas well away from the inundation zone and should be undamaged and able to assist in the response. The Port should assess whether they have any emergency equipment of their own and if/how it can be quickly moved out of the area and where it could be staged. Even seemingly non-emergency equipment such as forklifts, generators, large trucks, or loaders may be needed to assist after the event. The USCG Station Bellingham at the port may also want to evaluate its emergency equipment to determine what could be safely and quickly moved out of danger and where to locate it.

Activate Mutual Aid System as Necessary

Suitable for Port of Bellingham: Yes

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. 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.

Port of Bellingham mutual aid requests are covered in the Whatcom County Comprehensive Emergency Management Plan and the Whatcom County Tsunami Action Plan. In the event of an impending or occurring emergency like a tsunami, the Whatcom Unified Emergency Operations Center would be activated. Additionally, the Washington Emergency Management Division also has its own Mutual Aid System that could be activated as needed for more assistance beyond what Whatcom County could provide. However, in the event of a large-scale local tsunami many more locations in Washington will be affected and resources will be directed where they are needed the most.

Activate Incident Command at Evacuation Sites

Suitable for Port of Bellingham: Yes

During and after a tsunami event evacuation sites will likely be crowded with evacuees. There will be confusion from the public, and people may be injured, scared, and eager for answers and explanations. Activating an Incident Command at the evacuation area(s) can help to provide clear and direct leadership, chains of command, and span of control. It will be important to have qualified authorities who understand the Incident Command System (ICS) and how it operates filling those positions of leadership. Having an organized and structured command at these locations can help tame confusion, organize and calm evacuees, and prepare for response activities after the event is over.

The Whatcom County Comprehensive Emergency Management Plan is built on the National Incident Management System and the Incident Command System. This plan includes designated evacuation areas where Liaison Officers would be assigned at each area to relay information directly from Unified Command, providing clear leadership, chains of command, and maintain span of control. The Unified Command will be staffed by authorities from the Sherriff's department, police department, fire departments and EMS services. Port staff are trained in ICS and can assist in any additional positions that may be needed, as a large-scale emergency will require a large-scale response.

Alert Key First Responders at a Local Level

Suitable for Port of Bellingham: Yes

For a comprehensive and smooth response to a tsunami event local first responders will play a key role in evacuation, closures, Incident Management, and post event response. Ensuring that these responders are aware of both the imminent risk and what response actions the Port and its staff are taking is key. The sooner responders are notified of the event and the actions taken, the sooner they can prepare equipment and personnel, and begin to assist in the response. It would be prudent to identify the anticipated first responder needs well in advance for both a local and a distant event. Once those needs are identified, the Port should determine who will need to be notified, how those notifications will be made, and who will be making the notifications. This will help avoid any confusion or duplication of effort and can help free up other personnel for other response measures.

The Whatcom County Comprehensive Emergency Management Plan and the Whatcom County Tsunami Action Plan outline how first responders will receive tsunami warning notifications. The plan also details which first responders will be needed and what their roles are to be in the response. Overall, there is little the Port staff will need to do for this response measure. The Port should, however, ensure they are aware of those plans and any changes made in the future. The Port should be sure to inform the county of any response plans they plan on undertaking and update the county if those plans change in the future.

Restrict Traffic Entering the Port; Aid Traffic Evacuating

Suitable for Port of Bellingham: Yes

One of the main goals of responding to a tsunami warning will be to evacuate all the people from the inundation area. To facilitate this a port should develop a strategy to restrict vehicular or foot traffic from entering the port area, while also helping to maintain a safe and orderly evacuation from the area. Restricting entry could include things like closing gates or blocking roadways with vehicles, while aiding evacuations could involve personnel to direct traffic with flags or hand gestures or utilizing temporary signage. Remember, the goal of an evacuation should always be safety, and tsunami warnings do not come during daylight only, so if personnel are to be used to direct traffic ensure they have high visibility clothing or vests and flashlights.

The Whatcom County Comprehensive Emergency Management Plan and the Whatcom County Tsunami Action Plan have a detailed section on evacuations and road closures during a tsunami warning. Given the Port's location, very few roads will need to be blocked to fully restrict access to the area while allowing for evacuation. The plan describes the exact locations where the roadblocks are to be set up to close off both the port area and the Fairhaven terminal. The plan calls for these roadblocks to be manned and maintained by the police department, fire department, or public works, and describes how they will also facilitate and aid evacuation.

Personnel to Assist Rescue, Survey and Salvage

Suitable for Port of Bellingham: Yes

A major part of the post-tsunami event response will be the rescue, survey, and salvage operations in the area. Once the waves finally recede and the area is safe to enter responders will be required first to engage in search and rescue actions if individuals remained in the area when the waves arrived. There may be survivors trapped under debris, or even pulled out to sea who will need rescue. Personnel will also be needed to survey the area to determine what areas are safe to enter, whether it be buildings, docks or wharfs, or other shoreside facilities. The harbor area itself will need surveying to determine if it is safe to enter with vessels and if the waves caused the movement of sediment to such a degree that the previous depths of the water have changed, how much and where. Finally, personnel will be needed to determine what or if facilities or equipment can be salvaged in any way, or if they are unsalvageable and will require removal.

At the Port of Bellingham, post-event search and rescue operations in the shore side inundation zone will be headed by teams coordinated and directed by the Unified Command operating at the Whatcom Unified Emergency Operations Center. Water side search and rescue operations will be the responsibility of the USCG. Depending on the severity of the event additional personnel may be needed, and Port staff could be needed to assist. To help streamline the effort it would be good to identify personnel who would be willing to assist in this operation in advance and clearly identify those volunteers to the county authorities. The survey of the suitability of travel in the Port's waterways due to the potential of altered water depth from sedimentation will likely be the responsibility of the US Army Corps of Engineers. However, the Port facility and equipment surveys will need to be completed by Port staff who are familiar with the area. Port staff should be identified for post-event surveys, clearly outlining the scope of their responsibility. It will likely require multiple individuals and they should be tasked with surveying the areas they are most familiar with. For instance, the Harbormaster might be tasked with survey of the harbor docks, wharfs, and equipment, while other staff may be tasked with surveying the Bellingham Cruise Terminal area, and others with the industrial facilities.

These roles should be determined in advance, along with development of criteria to be used to evaluate the facilities and equipment. Such criteria should clearly outline what would constitute a 'safe' entry and use, and what threshold would need to be reached to deem areas 'unsafe'. The Port could consider establishing a tiered system of determination such as: Safe, Potential for Repair and Use, and Total Loss. Finally, Port personnel will also be required to determine what facilities and equipment can be salvaged after the event. This item could be folded into the survey portion of the response or could be tasked to separate individuals depending on the number of personnel available and qualified to make such determinations. The salvage portion of response will require staff to evaluate, similarly to the survey portion, facilities and equipment and determine whether these items are useable, potentially salvageable, or a total loss requiring removal and replacement. It will be important to identify who will be evaluating these items, as well as how the determination will be made and based on what criteria. It could be based on a monetary threshold, or a time to complete repair and return to use. Regardless, these should be identified in advance, documented, and when possible exercised to make the post-event response as complete and efficient as possible.

Identify Boat Owners/Individuals Who Live Aboard Vessels; Establish Phone Tree, or Other Notification Process

Suitable for Port of Bellingham: Yes

In the event of a potential incoming tsunami, alerting and warning those who own boats housed in a port or harbor area will be important. Notifications could be simply an alert that there is potential for damaging waves incoming or could be reminders or instructions to either evacuate immediately and/or to not enter the area and remain away until authorities have given an all clear that it is safe to return. For those individuals that live aboard their vessels in the harbors this becomes extra important, as they will need to be instructed to evacuate immediately and to not return until the area is safe to reenter after the event is over. Establishing a list of each of these individuals will help to ensure that all of those who have vessels in the area are alerted. It would be wise to separate the group into two lists, first of boat owners/slip users and second of individuals who live aboard their vessels. Given the much higher likelihood of those that live aboard their vessels being in the inundation zone and needing to evacuate, these individuals should be contacted first to ensure that they are not in the area when the initial waves arrive. Notifications can be delivered through several ways such as a phone tree, emailed notifications, text-based messaging, or even by personnel in the harbor using loudspeakers. Remember, individuals may not be able to receive any one method of notification so the redundancy of multiple methods of notification should always be preferred.

The Port of Bellingham has already established comprehensive lists with contact information for boat owners, slip renters, and individuals living aboard their vessels in the Port's harbors. The current planned notification process of an impending emergency involves a phone tree, email notifications, and personnel using loudspeakers to announce the need for evacuation. While comprehensive, phone trees can break down and email notifications can be missed. The Port may want to consider adding a text messaging service to disseminate notifications to augment the current notification plan. As with other response measures it is important to document the planned actions as clearly and thoroughly as possible and test the system frequently to ensure an efficient and working response when needed.

Reposition Ships Within the Harbor

Suitable for the Port of Bellingham: For Local Event – No; For Distant Event – Review.

Using the current velocity maps ports can identify the areas likely to encounter the strongest and fastest currents during an event. Once identified, the port could determine if moving ships out of those areas of danger and placing them in locations less likely to experience strong currents would be beneficial. What ships would need to be moved and to where is something that should be determined well ahead of an event and detailed in a 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 damaging infrastructure and leaving the ships free floating to cause additional damage. There would need to be clear Standard Operating Procedures (SOPs) developed for this response which detail such instructions as: who would make the determination that ships should be moved; who is responsible for moving the vessel; and how long the vessels would take to be moved. These SOPs would need to be exercised on a regular basis to ensure a smooth response when the time arose.

At the Port of Bellingham, the anticipated current velocities involved with a local event may exceed 9 knots and would therefore be extremely dangerous. These currents, coupled with the limited size of the harbors, would mean this is NOT a viable response measure for a local tsunami event. For a distant tsunami event where more time will be available before the first wave arrives, the movement of a limited number of vessels might be possible and would need to be evaluated further.

Remove Small Boats/Assets from the Water

Suitable for the Port of Bellingham: Review

One of the main dangers of a tsunami event is the amount of loose debris drifting freely in the water on the strong currents and rising and ebbing waves. Removing smaller boats and assets from the water can help to eliminate the potential for these objects to be damaged by debris or become drifting debris themselves. Removing boats or other assets from the water would be a time consuming and labor-intensive process. The effort may require shoreside boat lifts or cranes, or vehicles and trailers at the ready. Any equipment needed to remove vessels from the water would also need to be able to withstand 5-6 minutes of shaking from a CSZ earthquake for a local event. The effort would have to be extensively planned in advance and well organized during the process to avoid danger from congestion or confusion. However, the port may determine that certain boats or assets would be integral to recovery after the event and may choose to remove those in advance of the wave arrival. Vessels such as fire boats, law enforcement vessels, or vessels used in water-based search and rescue might be of sufficient value to necessitate removal from the water. Additionally, the amount of time available prior to dangerous wave arrival would need to be considered. There may not be enough time to remove assets for a local event, but a distant event's longer wave arrival time may allow for asset or vessel removal.

At the Port of Bellingham, the US Coast Guard is the Authority Having Jurisdiction on the water. However, they may not be able to provide near-shore search and rescue activities due to limitations in the size and capacity of USCG Station Bellingham. The Unified Command at the Whatcom Unified Emergency Operations Center would include Station Bellingham and would determine how to conduct any search and rescue required. The vessels utilized by USCG Station Bellingham are most likely too large to remove from the water in the amount of time available. If there are other smaller ships or assets of sufficient value to the Port or recovery effort, those would need to be identified and a detailed plan for how to remove them would need to be developed.

Remove Hazardous Materials Away from Water

Suitable for Port of Bellingham: Review

The destructive nature of tsunami waves inundating dry land causes many shoreside items to suddenly become debris. This hazard becomes even more dangerous if the debris is or contains hazardous materials. Barrels of waste oil, hazardous chemicals used in manufacturing at the Port, or any other types of hazardous waste can be turned into debris by the waves breaking open and spilling or spreading their contents. The spilling, moving, or spreading of hazardous materials can then lead to pollutants in the water or spread over the land, leaving an even larger and more involved mess to clean up after. If possible, with the time available before the first wave arrival some of the more portable or dangerous materials should be quickly moved to a staging location outside of the inundation area.

The numerous industrial and manufacturing businesses located on the Port's properties on Bellingham Bay are sure to use and store chemicals and materials that would be deemed hazardous. The Port would need to determine if these materials are all possessed by tenants of the Port and not the Port itself. The Port may determine that it does not have or store any hazardous materials, and that any hazardous materials on the property are possessed by tenants. In this case the Port should ensure tenants are aware of the dangers from a tsunami event, the potential for hazardous materials to be spilled and spread during such an event, and encourage tenants to secure, harden, or remove these materials. The storage and handling of these materials may not be the responsibility of the Port. However, if materials spill during a tsunami event the Port will be expected to assist in cleanup and recovery, so every effort to encourage mitigation of these materials in advance will prove a benefit in the long term.

Remove Buoyant Assets Away from the Water

Suitable for Port of Bellingham: Review

Some of the easiest items to become debris during a tsunami are items that are buoyant. These items that float easily on the water are some of the first things to be lifted by the waves and turned into additional debris that can become dangerous. Items such as floats or buoys are obvious, but other items like empty drums, barrels, or buoyant manufacturing or fishing supplies can easily become dangerous floating debris. Any items that will easily float and do not need to be near the water should be moved outside of the inundation zone when possible. Items that may easily float but need to remain in the inundation area should be secured as much as possible. While a large local source tsunami wave would most likely pull loose any moderately secured buoyant asset, they may remain secured during a smaller distant event.

The Port of Bellingham would need to inventory its property and facilities for any buoyant assets to determine whether any buoyant items are owned by the Port or by tenants of the Port. For any buoyant items in the inundation zone that are owned by the Port it should be determined if those assets can be relocated out of the inundation zone, or if they need to remain in the area. If items can be relocated, they should be moved to somewhere outside of the inundation zone and staged there until needed. If the buoyant items are needed in the inundation area they should be evaluated as to whether there could be a way to secure them as much as possible. If the items cannot be relocated or secured, they should be evaluated as to if they could be removed after an alert but before the wave arrival. If it is determined that buoyant items within the inundation zone are owned by tenants of the Port, then the Port should ensure that all tenants are aware of the dangers of a tsunami event and the potential for buoyant items to become dangerous debris during such an event. Tenants should be encouraged to either secure, harden, relocate, or plan for removal of any buoyant items.

Move Boats and Ships out of Harbors

Suitable for Port of Bellingham: No

For ports that lie on the coast of the open ocean, relative safety for ships can be found at depths of 30 fathoms (180 feet) for a distant tsunami and 100 fathoms (600 feet) for a local tsunami. In some locations the distance to these depths is short and, depending on the time it will take for the first wave to arrive, evacuation of ships and boats to sufficient depths may be possible. The evacuation effort would need to be planned, orderly and controlled to avoid dangers associated with congestion in the waters. Some locations have already developed and even implemented such plans. On the island of Oahu in the state of Hawaii the concept of ship evacuation has already been planned for. Upon receipt of a tsunami warning all ships that can be moved from the harbors in the time before the wave arrival are to be moved into the designated staging area beyond 100 fathoms depth. Captains of vessels are to receive the warning and immediately head to their ships and then carefully pilot them to one of the two designated zones. Commercial ships are staged in one area, and recreational vessels in another, separated by an exclusion area to allow for travel and to keep the vessels apart during the wave activity. A diagram of the staging areas for the Honolulu area is shown in figure 29.

This approach may be possible for some ports or harbors on the Pacific coast of Washington depending on the length of time it would take vessels to reach sufficiently safe depths. However, this mitigation measure is unlikely to be usable by ports on the inner coast given the relatively narrow nature of the inner waterways as compared to the open ocean, time and distance to deeper waters, and the amount of congestion in the few areas that may meet the depth requirements. This approach is wholly unsuitable for the Port of Bellingham, as the nearest location with sufficient depth is much too far to reach in the time before the first wave arrives.

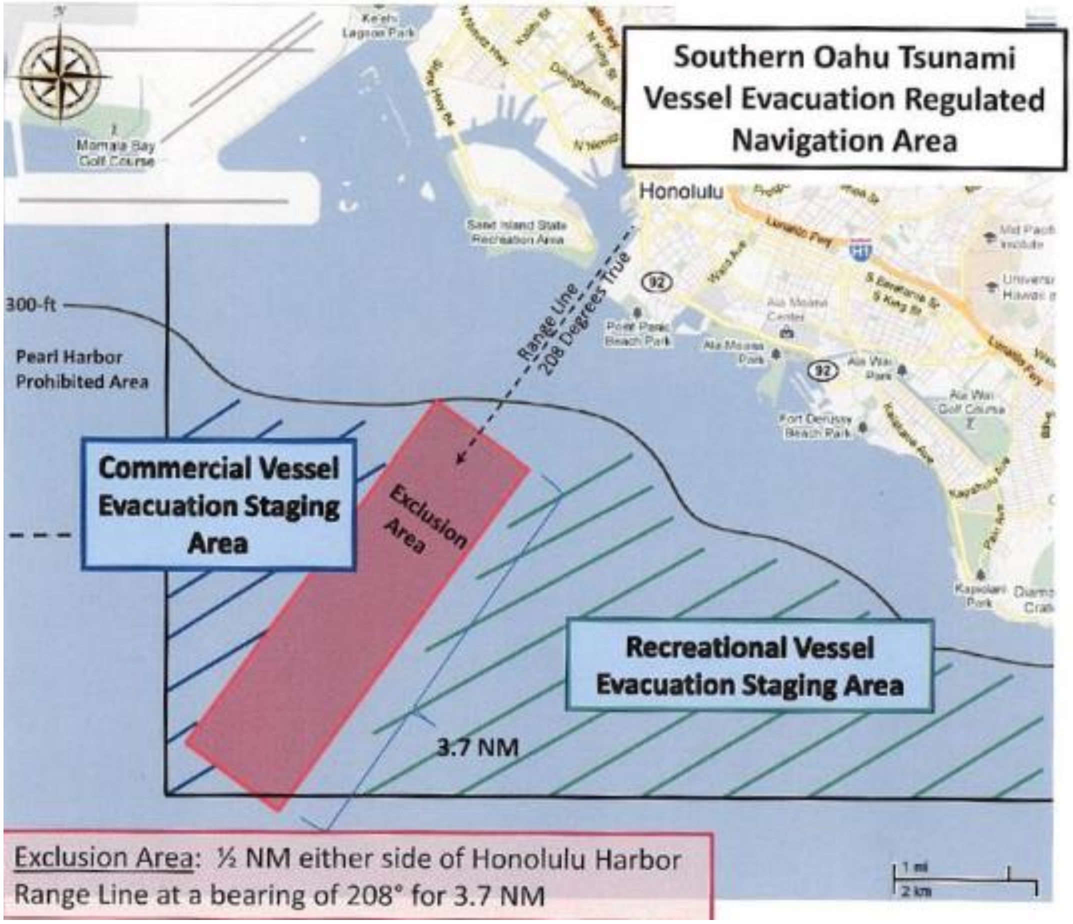


Figure 29: Tsunami vessel evacuation area for South Oahu showing line of 100 fathom depth.

Move Large Deep Keeled Ships from Harbor Entrances

Suitable for the Port of Bellingham: No

The strongest tsunami currents are often seen near the narrow entrances of harbors. Large deep keeled ships that are moored in these locations are in the most danger of being ripped from their moorings and left drifting freely. Much like repositioning ships within the harbor, given enough warning time a port could choose to use this time to direct large deep keeled ships to move to less dangerous places. As a more long-term solution ports could move the berths for larger ships to areas away from harbor entrances permanently. Note that this response differs from repositioning ships within the harbor, as this applies only to large deep keeled ships that are near the mouth of the harbor where currents are strongest, and not to other large ships in the harbor.

At the Port of Bellingham most ships in the harbor are of the small to medium sized variety, and few berths seem to be directly located by the harbor entrance (with some exception in the inner basin). This response measure would most likely not be feasible.

Section 3: Mitigation Guidance for the Port of Bellingham

Mitigation measures are taken to reduce risk and protect lives and property before an emergency happens. They can require a significant amount of time, investment, and expertise. Some examples include strengthening cleats and moorings and installing stronger or taller dock piles. Here we present and explain these mitigation measures with visuals to help you understand what they would look like after completion, as well as identify the parties responsible for undertaking those measures.

Mitigation Measures	Difficulty for Port of Bellingham
Strengthen cleats and single point moorings	Easy
Debris deflection booms to protect docks	Easy
Install tsunami warning signs	Easy
Increase size and stability of dock piles/ increase height of piles to prevent overtopping	Medium
Increase flexibility of interconnected docks	Medium
Improve movement along dock/pile connections	Medium
Reduce exposure of petroleum/chemical facilities and storage	Medium
Prevent uplift of wharfs/piers by stabilizing platforms	Medium
Equipment/assets to assist response activities	Medium
Fortify and Armor Breakwaters	Hard
Improve floatation portions of docks	Hard
Deepen or dredge channels near high hazard zones	Hard
Move docks and assets away from high hazard zones	Hard
Widen size of harbor entrance to prevent jetting	Hard
Construct floodgates	Hard
Construct breakwaters farther away from harbor	Hard

Table 5: Mitigation measures and relative difficulty.

Mitigation Measures for The Port of Bellingham

Strengthen Cleats and Single Point Moorings

Level of difficulty at Port of Bellingham: Easy

Figure 30: Cleat ripped from dock.

The cleats and mooring points used to anchor vessels to docks will need to withstand extreme forces during a tsunami event. Vessels which pull free from their moorings during an event and end up floating freely will quickly become part of the massive amounts of debris moving in the water. Vessels as debris will lead to increased collisions, damage, and can cause even more vessels to also break free, increasing the amount of free-floating material even more. 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 (see figure 30). 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 events, 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, as shown in figure 31.

Figure 31: Bollard with backing plate to distribute force.

The Port of Bellingham's miles of docks contain thousands of cleats, bollards, and other mooring points. The Port should inventory the numbers, types, approximate ages, and relative condition of these mooring points to better understand their condition and suitability. While replacing or retrofitting all the mooring points is surely unnecessary, once evaluated and classified the Port can have a better understanding of what will need replacement and when. They can then focus on replacing old, degraded, and under-rated equipment first. When replacing the mooring points the Port should purchase equipment as described above, that is strong enough to withstand the weight of the vessel moored, even with exceptionally strong drag, and is attached in a way that will not be susceptible to being broken or pulled free. While the amount of mooring points that may need replacing may seem daunting, this is likely one of the easiest and lowest cost options available for tsunami mitigation.

Debris Deflection Booms to Protect Docks

Level of Difficulty for Port of Bellingham: Easy

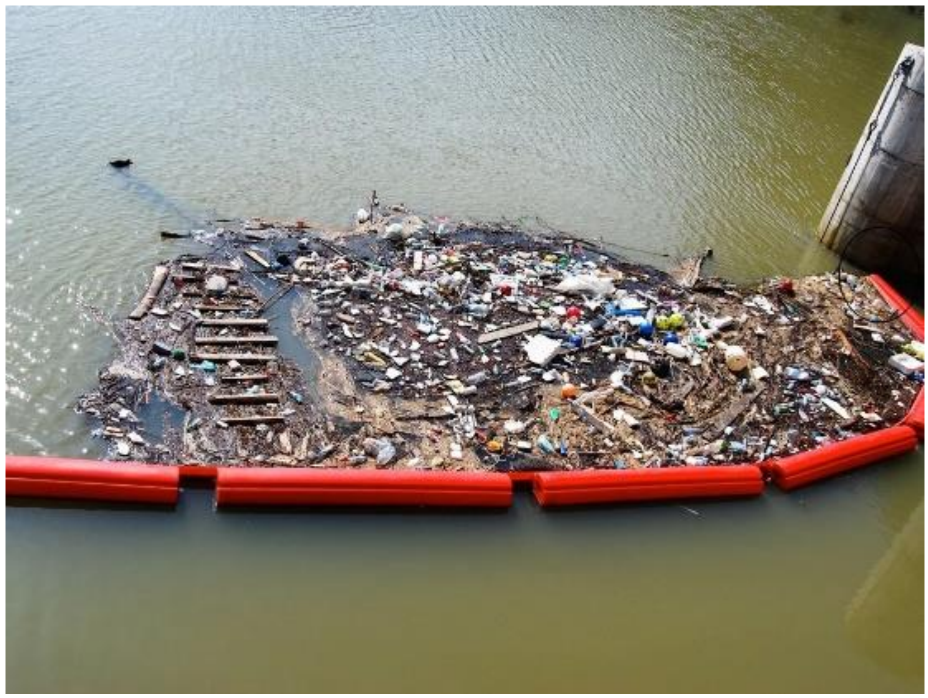


Figure 32: Debris deflection boom.

Debris deflection booms are installed in harbors to protect the dock structures from damage caused by floating debris. The booms are installed between the open water and the docks to deflect any floating debris in a different direction and keep the debris from striking and damaging the dock structures or the vessels moored there. 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 32. 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 event. Even a partial reduction in the amount of debris carried on tsunami waves would help to reduce damage from collisions between debris and vessels or dock structures. Debris booms would 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.

The Port of Bellingham could consider the placement of debris deflection booms to protect the dock infrastructure inside the harbor areas. Since these structures require little construction beyond the placement of sturdy pilings that would be strong enough to withstand the strain placed on the boom from the waves and debris, installation of a boom would be simple. The addition of new structures inside of the harbor area would require evaluation on where to place booms to offer the most protection of structures and vessels while also allowing for vessel travel in and around the harbor unimpeded. The Port would also need to ensure that harbor users are aware of the new structures and avoid collisions with them. It is possible that due to the configuration of the harbors and dock systems the Port may determine that boom placement is not feasible, as the booms may not allow for unimpeded travel within the harbor. However, any location that booms could be used would help lessen the amount of debris impacts and resulting damage associated with tsunami waves.

Install Tsunami Warning Signs

Level of Difficulty for Port of Bellingham: Easy

Installing tsunami warning signs is the easiest and most cost-effective mitigation measure that a port can take to reduce tsunami injuries and casualties. The simple signage can help to educate harbor users of the danger of tsunamis in the area and can help direct individuals to safety during an evacuation of the area. Signs are cheap, installation is easy, and upkeep is minimal. Signage can be posted along roadways and trails to alert people that they are entering or leaving a tsunami inundation zone, so individuals entering the area know of the need to evacuate if a tsunami warning is issued. Signage designating the location and direction of evacuation routes can be posted to help people find and follow the established evacuation routes quickly during an evacuation. Standardized signage has been created to designate the extent of inundation areas as well as to designate and define evacuation routes. Additionally, signage can be created to educate and inform people of anticipated tsunami inundation extent in the area, evacuation route maps, and even 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 33.

Figure 33: Tsunami evacuation kiosk Oceanside, California.

The City of Bellingham already has evacuation route signs posted along Roeder Avenue, the main road along the Bellingham waterfront. However, the Port does not have signage to inform users that the area is a tsunami hazard zone, and the evacuation route signs are widely spaced and not visible at every intersection. The Port should evaluate every exit from its facilities and post evacuation route signage and directional arrows at every point along the established evacuation routes that would require evacuees to make a decision regarding where to go. They should also post tsunami hazard zone signage to make users aware of the risk of tsunamis in locations where people gather or frequent. The Port could also consider discussing with the city about posting entering/leaving tsunami hazard zone signage along the roads that enter the area. All these signs are available in Washington for free from the Emergency Management Division (as stock allows). The Port would only need to cover the cost of installation and minimal upkeep of the signs making this the most cost-effective mitigation measure available to the Port. The Port could go further with the creation and installation of informational kiosks that include the Bellingham area evacuation walk map and general tsunami information.

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

Level of difficulty for Port of Bellingham: Medium

Figure 34: Docks lifted off pilings due to extreme water level changes.

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 be sufficiently high enough to float docks off the top of the pilings, leaving them unattached and floating freely (Figure 34). The strong currents from tsunamis can also, through scouring or drag on the docks and vessels attached to them, pull pilings from the ground. Pilings that are pulled loose also lead to a dock unattached to the sea floor and floating in the dangerous waves. Untethered, freely floating docks pose a danger in a tsunami event, 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 even during a tsunami event, 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. 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 and more resistant to scouring and keep them from pulling out of the soil.

The two harbor basins of Squalicum Harbor contain well over 5 miles of docks supporting the 1,400 slips for vessels. These docks are supported by pilings numbering in the thousands. Most of the pilings are in newer or very good condition and so, assuming they are installed at a sufficient depth in the sea floor, they are most likely very structurally sound. These pilings should resist much of the shear forces from tsunami waves and are unlikely to break or pull free. However, the height of the pilings is likely insufficient to accommodate the water level rise expected from a local source tsunami, as shown in figure 35. In the most extreme case of a distant source tsunami, such as from an Alaskan event, if a maximum wave arrival coincided with an extreme high tide, the piling heights may still prove insufficient. While replacement of all the pilings in the harbor with taller ones would be unfeasible, the Port could take the anticipated inundation depths into account when replacing old pilings in the future. Pilings will need replacement on a more regular basis than larger structures like breakwaters. While adding a few feet onto the height of each new piling will increase the cost it would not be nearly as cost prohibitive as many of the larger mitigation actions.

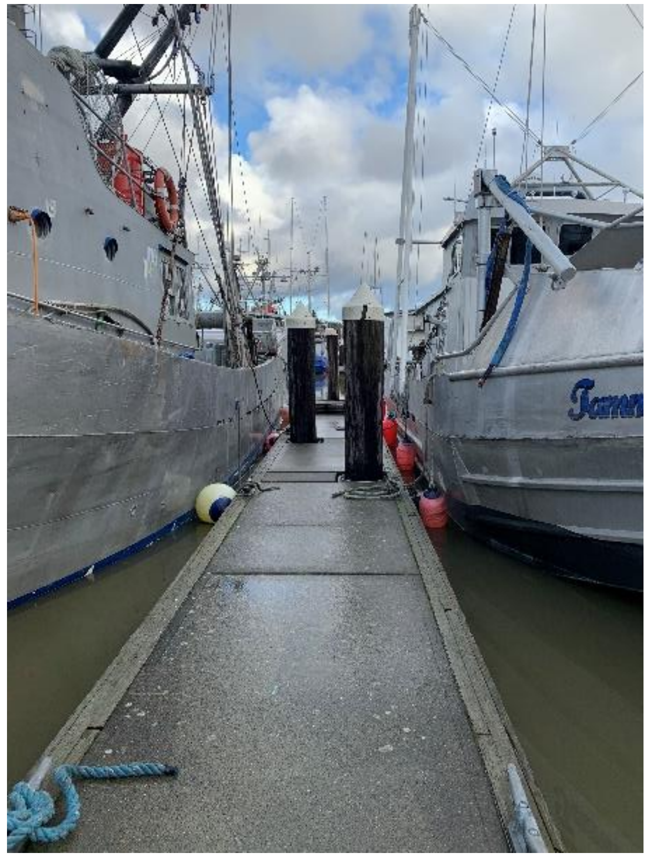


Figure 35: Newer strong pilings at Squalicum Harbor may prove of insufficient height to anchor docks during tsunami inundation.

Increase Flexibility of Interconnected Docks

Level of Difficulty for Port of Bellingham: Medium

The rapidly changing water levels, extreme waves, and unpredictable currents associated with tsunami events will test the flexibility of any dock system. When an interconnected dock cannot handle the extreme changes during the tsunami event it will likely break at the joints connecting two dock sections, as in figure 36. The refracting waves will move docks in both horizontal and vertical directions in ways docks will not have been subjected to prior. Post-event, any docks that are torn apart or broken will need extensive repairs at best and full replacement at worst. 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 of the dock sections can involve lengthening gaps between the sections to allow for increased movement or utilizing more flexible types of hardware to make the attachments.

The Port of Bellingham will need to evaluate how their interconnected dock systems are connected and how much flexibility is allowed by those connections. The connections should be evaluated not just on the ability of each section to float independently up and down (vertically), but also for flexibility side to side (horizontally). The bouncing and refracting waves inside the harbor area will move docks in all directions, sometimes in rapid succession. Docks that are unable to flex quickly in multiple directions should be considered for upgrades or retrofits of the connecting hardware and equipment. Docks upgraded should make use of as much space between sections as possible, and should be connected with strong, sturdy hardware that allows for as much movement as possible while remaining intact.

Figure 36: Broken dock in California from tsunami waves.

Improve Movement Along Dock/Pile Connections

Level of Difficulty for Port of Bellingham: Medium

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 get 'jammed' 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

Figure 37: Piling hoop hardware that is more prone to binding during movement.

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 (shown in figure 37) 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 (Figure 38) helps to avoid binding issues and promote smooth movement even more.

The Port of Bellingham should inventory the types of hardware used to connect docks to the pilings and evaluate those types based on the amount of movement they will allow. Connection hardware that is robust, allows for movement, and incorporates means to facilitate movement, like rollers, should be noted and maintained in working order. Docks utilizing connection hardware that is weaker, could be prone to breaking or binding, or is older or damaged should be prioritized for retrofits or replacement. Replacement hardware should be of sufficient strength to withstand extreme wave action and able to move smoothly as much as is feasible for the intended use.

Figure 38: Through deck piling hardware with rollers to promote smooth movement.

Reduce Exposure of Petroleum/Chemical Facilities and Storage

Level of Difficulty for Port of Bellingham: Medium

Since ports and harbors are where ships go for refueling and many routine maintenance procedures, these areas will have a number of facilities that utilize and store petroleum and chemical products. Damage to or destruction of these facilities or the locations and containers that store petroleum or chemicals during a tsunami event can cause an extremely widespread hazardous material spill and contamination. Some ports may even have chemical processing facilities or oil refineries, in addition to normal vessel fueling facilities and manufacturing plants that utilize chemicals. 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 been known to combust even on top of the water; the fuels can also 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 as well as refineries and extremely large fuel storage tanks should be located well outside the inundation zone. If that is not possible then the next best solution would be 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 if possible, moved to locations at less risk for damage or destruction, or hardened as much as possible to withstand the earthquake and tsunami waves.

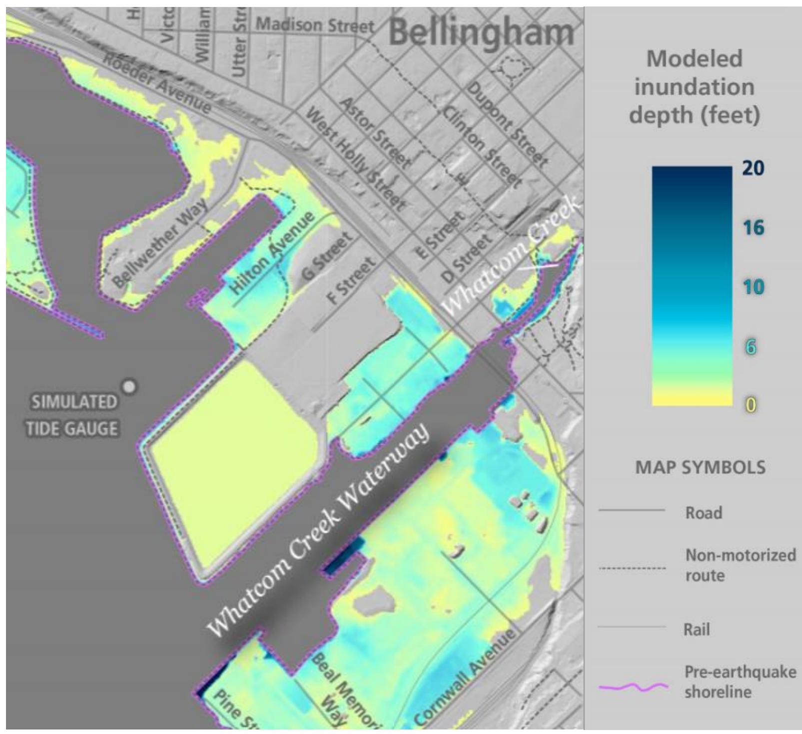


Figure 39: Close up of modeled inundation from maximum considered distant tsunami at the Port of Bellingham.

The Port of Bellingham does not have any refineries, chemical processing plants, or extremely large storage tanks at its facilities on Bellingham Bay. However, the Port does have tenants who provide fueling and maintenance services that require storage of substantial quantities of fuel and vessel maintenance chemicals. Additionally, there are several manufacturing facilities on Port property that store and use many different industrial chemicals in their manufacturing processes. The Port should inventory the types, locations and storage facilities of all petroleum and chemicals stored and utilized on Port property. The Port should assess whether some of these chemicals could be stored outside of the inundation zone and moved onto the property only when needed. Of the materials that are needed on a regular basis it should be assessed if the storage tanks or facilities would withstand an earthquake and tsunami wave. When possible, these facilities should be moved or relocated to areas on the property that are at less risk for inundation. While a local event will produce widespread inundation of such depth to likely cause damage to the entire area, the inundation from a distant event has more variation with certain locations expected to receive inundation less than a few feet and some locations no inundation at all (such as most of the area east of the former Aerated Stabilization Basin on figure 39). These locations would be ideal for storage of chemicals and hazardous materials that cannot be moved out of the inundation zone entirely. Even in these locations it would be wise to make every attempt to harden or retrofit any storage facilities to withstand a potential tsunami wave.

Prevent Uplift of Wharfs/Piers by Stabilizing Platforms

Level of Difficulty for Port of Bellingham: Medium

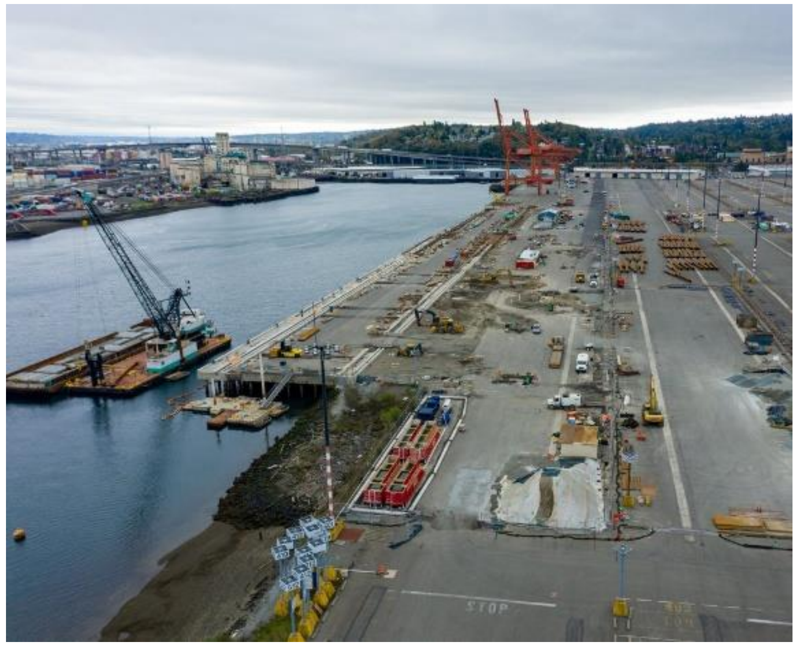


Figure 40: Wharf construction at the Port of Tacoma.

Wharfs and piers differ from docks in that they are stationary platforms, often built atop pilings driven into the sea floor, that do not move with the waves or tides. Wharfs are utilized to load and unload goods from larger vessels such as ocean-going barges or seafood processing ships (figure 40). Many wharfs were built decades ago and repairing the foundation of such a large structure is done only when absolutely required. Even conducting evaluations of structural integrity can be difficult due to the sheer number of foundation pilings, connections, their location both in and out of the water, and the need for specially trained personnel or contractors to perform the checks. Tsunami waves and currents can cause pilings to fail under a wharf from scouring or damage from debris. The tsunami inundation can also lift part or all the deck of the wharf off the pilings if the connections between the deck and foundations are not secure and robust. Stabilizing the platforms of a wharf can mean simply increasing the number and strength of the piling to platform connections, or it can be a more complex undertaking like enhancing the connections and adding additional structural rigidity through braces between pilings themselves, making the entire structure more stable.

The Port of Bellingham has numerous piers and wharfs within Squalicum Harbor, at the Bellingham Shipping Terminal, and at the Bellingham Cruise Terminal in Fairhaven. These piers and wharfs are utilized to load and unload fishing and shipping vessels, passenger ferries, and to access drydocks for ship maintenance and repair. Some of these wharfs were likely constructed many years ago and could require stabilization. The Port should, during routine review and inspection, assess and categorize the stability of the foundations and connections between the pilings and the platform structure. Wharf or pier platforms that simply sit on top of the foundation pilings should be prioritized to be retrofitted with connection hardware. Platforms that are attached to the foundation with older or degraded hardware should be retrofitted as well. The foundations should be assessed to determine if additional braces would also be required to enhance stability.

Equipment/Assets (Patrol/Tug/Fireboats/Cranes, etc.) to Assist Response Activities

Level of Difficulty for Port of Bellingham: Medium

Post-tsunami event response will be a complicated effort involving a large number of personnel and equipment. Vessels will be needed to patrol and search the water for survivors or casualties, as well as to tow or 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 the vessels, facilities, or on the floating debris (figure 41). 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 the port property. Large ports 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 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 plan, including agreements with local entities to rent, borrow, or have use of any equipment that would be needed to respond after a tsunami event in their port.

Figure 41: Bellingham Fire Department fireboat located in Squalicum Harbor.

The Port of Bellingham does not have all the equipment required for a post-tsunami event response. Whatcom County has a FEMA approved Debris Management Plan that includes agreements with local contractors to access the equipment that will be needed to respond after a disaster. The Port should evaluate the type and amount of equipment that will be needed post event and review the county response plan to determine whether additional equipment beyond what is listed might be needed. Once determined, the Port can either engage in discussions with the county to add additional equipment to the list or work to get access to that equipment themselves. The Port should also ensure that if they are relying on other entities for assistance, such as the Coast Guard for water rescue or tug companies for towing services, that those entities are aware of this and will be sufficient to serve in that capacity, if possible.

Fortify and Armor Breakwaters

Level of difficulty for Port of Bellingham: Hard

Figure 42: Breakwater failure in Japan after 2011 Tohuku Tsunami.

Breakwaters are designed to absorb and deflect strong wave action to protect ships and vessels from rough seas. Unless built to be extremely tall, breakwaters are unlikely to be able to block tsunami waves. The waves would likely overtop the structure allowing the inundation to enter the normally protected area. The strong waves and currents from a tsunami event 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 an event could cause the breakwater to fail, as pictured in figure 42, allowing even more water to flow into the area. Sudden gaps in the breakwater can also create new unpredictable and dangerous currents.

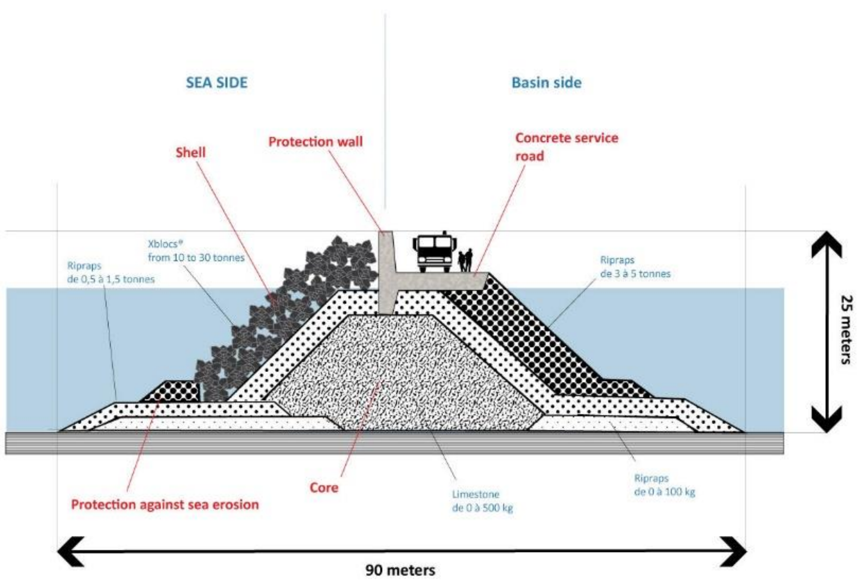


Figure 43: Cross section of a fully fortified breakwater.

Any damage to breakwaters will also need to be repaired post event, and if damage is severe enough could require full replacement of the structures at considerable time and cost. 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 that would be able to withstand much more damage from 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 43. Armoring implies covering the sea side 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 so they interlock and are less likely to break loose in strong wave and current action as shown in figure 44.

Figure 44: Armored breakwater.

Both armoring and fortifying breakwaters are time, resource, and cost intensive processes. 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, the amount of cost and effort may lead this option to only be more seriously considered when building new breakwaters or when the span of life is over for current breakwaters and they require replacement.

The Port of Bellingham has more than ¾ of a mile of breakwaters, and well over ½ mile of reinforced shorelines on its property, not counting the reinforcements around the water retention center. As mentioned above, fortifying and armoring breakwaters can be a long and resource intensive process. With so much breakwater to strengthen the Port would likely only seriously pursue this option when rebuilding already damaged structures or when constructing new ones. Even then the process will likely take years to be complete.

Improve Floatation Portions of Docks

Level of Difficulty at Port of Bellingham: Hard

The rapid onset of tsunami waves can rapidly over-top docks causing them to sink and break apart if the docks are not sufficiently buoyant. It may appear that since they are floating and rise and fall with the tides and waves, that all docks have sufficient floatation portions under them. However, certain styles and materials of floating dock structures are in fact much more buoyant than others. Many docks are made 'pontoon' style where tubes of buoyant materials (sometimes filled with foam) run in a parallel track with a platform built on top (figure 45). 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 46). These styles, while common, will not prove to be 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 (similar to Styrofoam) which spans the entire dock width and length (figure 47). The increased buoyancy of full floatation docks will do the best at handling the extremely fast changes in the water depths that accompany tsunami waves.

Figure 45: A pontoon style dock.

The Port of Bellingham most likely already maintains records of its dock structures, ages, and construction types. These records should be reviewed and the Port should consider replacing any pontoon style or partial block section docks with docks that are constructed on full length and width floats. While time consuming and potentially expensive, investments in dock structures that have increased floatation have benefits beyond just tsunami mitigation. Docks with increased buoyancy will last longer over time and will be able to better withstand other potential emergencies like floods, storm surge, and king tides. If docks with full floatation sections prove too expensive, the port should consider spacing the flotations as close as monetarily feasible to increase buoyancy as much as possible.

Figure 46: Dock built on floating blocks.

Figure 47: Docks built on full floatation system.

Deepen or Dredge Channels Near High Hazard Zones.

Level of Difficulty for Port of Bellingham: Hard

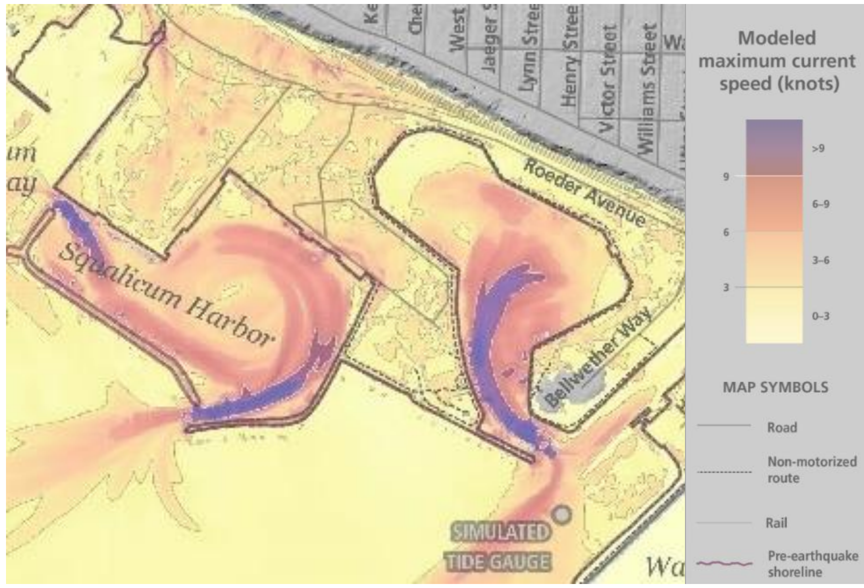


Figure 48: Close up of anticipated current velocities in Squalicum Harbor for a CSZ event, for full map see figure 18.

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 on to 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 event hazards are highest. Deepening of these locations through dredging or other means will not eliminate the hazards but can help to lessen their effects. The process of dredging or otherwise deepening channels is a complicated, involved process that will require 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 going to be worthwhile as a standalone measure. However, sedimentation builds over time and eventually all harbors, ports, and channels will require dredging for maintenance purposes. It is more likely that ports would choose this time of regular maintenance to utilize hazard maps to determine the areas of high hazard and deepen them as much as feasible.

The hazard maps developed for the Port of Bellingham have identified a few key locations in the harbor areas at an increased hazard risk. Specifically, the areas near Squalicum Harbor's entrances are at high risk for extreme currents; however, this is more likely from the 'jetting' effect of the water moving through the narrow passage and not from the depth. Locations around the edges of the outer basin and inside the entrance of the inner basin have the potential for extreme currents as well (figure 48). It is possible that these locations are subject to higher projected current speeds because of how the water will flow through the entrances and move through the harbor. In this case, deepening the harbor areas will most likely not help much to alleviate the current velocity hazard.

While deepening the harbor might not help much with currents, another hazard facing the Port of Bellingham is the extreme minimum water levels during the receding of a tsunami wave. As can be seen in the close-up of the modeled minimum water level map from the maximum considered distant tsunami (figure 49) the drawdown will leave some portions of the harbors with a depth of less than 3 feet of water. This level of water risks some vessels docked in those areas being grounded and potentially swamped by the next incoming wave. Therefore, any deepening or dredging in these specific areas will help to alleviate the risk of vessel grounding. As mentioned above, the cost and time inputs for deepening operations mean this would likely be done when regular dredging maintenance is required. When maintenance dredging is required, the Port should consider additional deepening in these locations to maximize the benefit and help to lessen the grounding hazard.

Figure 49: Close up of modeled minimum water level from distant tsunami at Squalicum Harbor, for full map see figure 23.

Move Docks and Assets Away from High Hazard Zones

Level of Difficulty for the Port of Bellingham: Hard

Once a port has been able to identify the areas that are more likely to experience significant tsunami hazards, they can consider relocating the port infrastructure away from these areas. Docks and vessels in the highest of hazard areas are at the most risk of damage or destruction during a tsunami event. 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, adding to the debris moved around in the water. 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 had 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 event were to occur.

The Port of Bellingham's Squalicum Harbor will likely not be able to benefit from this measure. The two harbor basins are configured to shelter the maximum number of vessels possible in the space they have. While there are some identifiable high hazard areas within the two harbor basins there is not really space to relocate any infrastructure to areas of less hazard without removing or eliminating docks and slips. Given the size of and space constraints within the harbor area and the size of the area that could be considered high risk, the amount of infrastructure and number of slips would likely need to be reduced by 40-50% or more. As this kind of reduction is economically unfeasible, the Port should instead focus its mitigation efforts on strengthening and improving the infrastructure in the high hazard areas rather than moving it.

Widen Size of Harbor Entrance to Prevent Jetting

Level of Difficulty for Port of Bellingham: Hard

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 amount of rough seas that can pass through them. While the narrow design helps keep the harbor areas calmer during typical rough conditions, they become much more dangerous during a tsunami event. The extreme water level changes and surges of water that are produced by a tsunami will become amplified at the narrow entrance points. Here the water will speed 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. Additionally, changing or altering the size of entrances to harbors is an involved process to alter the size and shape of the breakwaters that form each side of the entrance. 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.

The tsunami modeling done for the Port of Bellingham shows the potential for extreme jetting around the harbor entrances. The highest anticipated current velocities, expected to be in excess of 6 knots for a distant event and 9 knots for a local event, are expected at the entrances to both harbor basins. Whether the Port could conceivably widen these locations and see a reduction in the anticipated currents is a complex question. As stated above, the decision to widen entrances is based on a delicate balance between sheltering vessels from everyday surges and rough seas and avoiding the most extreme effects of a tsunami event. This decision would need to be evaluated thoroughly with engineers and tsunami modelers to determine whether the benefits of a widened entrance to reduce current speeds is worth the cost of potentially opening the harbor to reduced shelter during normal storms and rough seas.

Construct Floodgates

Level of Difficulty for Port of Bellingham: Hard

Figure 50: Floodgates in Fudai, Japan.

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 events, and even during large events in locations with less inundation. Japan has constructed a number of massive floodgates that proved effective against tsunami waves, like the floodgate pictured in figure 50. 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 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. Floodgates are the most effective when waterways have a narrow entrance to a bay, port, or harbor, allowing one set of gates to protect the entire area.

The Port of Bellingham will not likely consider the construction of large floodgates. The wide-open configuration of Bellingham Bay would require floodgates to be built at each entrance to the harbors and would only protect those locations. Floodgates could not be used to protect the Bellingham Cruise Terminal or the Bellingham Sipping Terminal. Even at Squalicum Harbor, such construction would first require the enlarging and hardening of the breakwaters at significant cost, labor, and time. Given the major effort to protect only a small part of the port, floodgates are not suitable for the Port of Bellingham.

Construct Breakwaters Farther Away from Harbor

Level of Difficulty for Port of Bellingham: Hard

Breakwaters confine and shelter harbors, providing protection from storm surges, strong waves, and ordinary floating debris. During a tsunami event, however, these same breakwaters constrict extreme and 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 event (Figure 51). 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 fairly straight.

Figure 51: Breakwater protecting the harbor in Hilo, Hawaii built far out from harbor area.

The Port of Bellingham's Squalicum Harbor, seen in figure 52, is protected by breakwaters built immediately adjacent to the harbor areas. These breakwaters enclose the harbor and create a very confined basin that will amplify tsunami effects. The tsunami modeling of the Port area shows that within the harbors extreme currents will be produced as the tsunami waves enter and recede from the area. While moving the breakwaters to be further from the shore would enlarge the area and reduce the risk from the effects of tsunami waves, this is not a reasonable measure for the Port of Bellingham. It was noted that fortifying and armoring of breakwaters was a long term, labor and cost intensive undertaking. Construction of entirely new breakwaters (and possible removal of old breakwaters) is an even more complex and involved task. Construction of breakwaters farther from the harbor is a measure that would be undertaken by a port only when initially constructing a harbor, or in the unlikely event that a current breakwater needed removal or replacement.

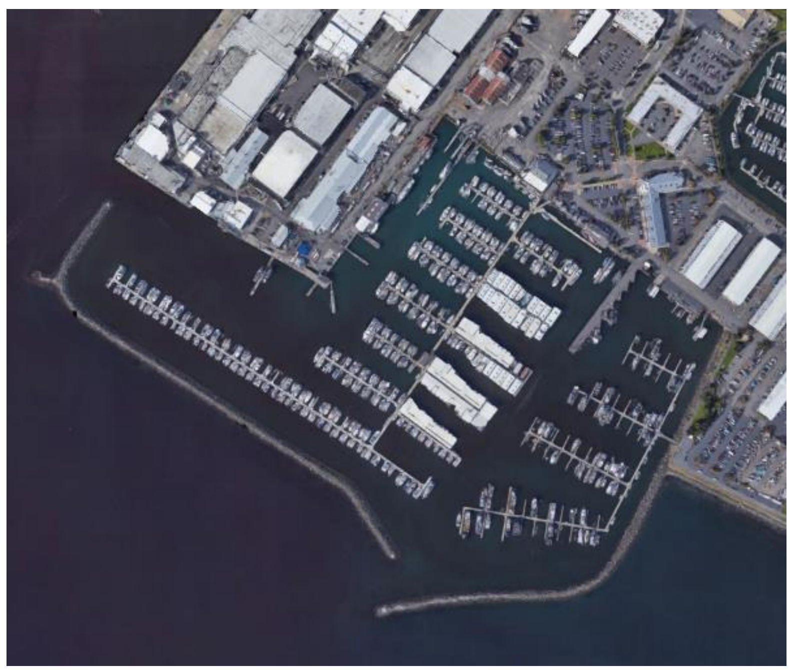


Figure 52: Squalicum Harbor north harbor's breakwaters built close to the harbor area.

Conclusion and Next Steps

The dangers posed from a tsunami to the maritime community in general, and the Port of Bellingham specifically, are extreme. A locally generated tsunami has the potential to decimate port infrastructure, destroy many vessels, and cause a high number of casualties within the tsunami inundation zone. This level of damage could lead to the Port being unable to operate in any capacity for a significant length of time, disrupting a key location used by the maritime community and leading to a significant loss of economic revenue for the surrounding area. A distant source tsunami, while posing less of a risk, still has the potential to cause significant damage to Port infrastructure such as docks and could lead to damage or destruction of many vessels located in the harbors. The time, money, and effort it will take to restore the Port to pre-event conditions will be significant.

This highlights the importance of assessing and understanding the hazard and risk posed by tsunamis. With this understanding, measures can then be undertaken to improve response capability and mitigate the risk as much as possible. These response and mitigation actions can help save lives, make the Port more resilient, and reduce the time it takes for the Port to recover, thus restoring an integral part of the maritime infrastructure and economy. They can also enhance the Port's resiliency to more frequent hazards such as extreme storm events, unusually high tides, and floods. Given the tsunami risk and the importance of the Port to both the maritime community and the local economy, every action taken to reduce this risk is a step toward creating a more resilient community.

Going forward, the Port of Bellingham can take steps and engage in actions in both mitigation and response that will make the Port more resilient and its customers, tenants, and the public safer in the event of a tsunami event. Some of these actions are relatively simple and easy to undertake, while others require more time, planning, and outside assistance.

To help mitigate the potential damage to port infrastructure and tenant property and reduce potential casualties, **it is recommended that the Port consider taking or augmenting these simple mitigation actions:**

- Strengthen cleats and single point moorings
- Install debris deflection booms to protect docks
- Install tsunami warning and informational signs

These mitigation measures are relatively easy and simple and will require few resources to accomplish while providing substantial benefits in reducing potential damage, injuries, and casualties for those who live, work, and recreate on the Port's properties.

The Port should also **review the following mitigation actions and decide if they are appropriate to further enhance Port resiliency:**

- Increase the size/stability and height of pilings to prevent damage and overtopping by docks
- Increase flexibility of interconnected docks

- Improve movement along connection points between docks and pilings
- Prevent uplift of wharfs/piers by stabilizing platforms

These mitigation actions will be more resource intense to undertake and fully implement, often requiring consultation with engineers or other experts. Despite the increased resource inputs to achieve these actions, the benefit of reduced damage to facilities and potential reduction in casualties make these larger mitigation actions worth evaluating and implementing wherever possible. The Port should evaluate these options and where appropriate work them into the Port's long-term planning for maintenance and future upgrades.

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

The Port of Bellingham is a member of the Whatcom County Emergency Management Council Interlocal Agreement for the provision of Emergency Management Services and is covered under the Whatcom County Comprehensive Emergency Management Plan and the Whatcom County Tsunami Action Plan. These plans have robust sections outlining tsunami response actions which includes evacuation, the standing up of incident command, and activation of mutual aid systems as needed. However, there are response actions the Port should take on its own that are beyond the scope of those plans.

Some of the easiest response actions the Port is recommended to take are:

- Shut down infrastructure before tsunami waves arrive
- Secure boat and ship moorings
- Identify boat owners and individuals who live aboard their vessels, establish multiple processes to notify them of a tsunami, practice those processes, and maintain and update those records regularly

These response actions require little in the form of planning, time inputs, or other resources to accomplish. Some of these actions may already be in the planning stages or implemented in some form, but every attempt to enhance and improve on these actions will assist the Port's response to an event.

Once the Port has exhausted all the easier measures to create a more robust response to a tsunami, they should review some of the more difficult or resource intense response actions to develop the most comprehensive response possible.

Some response measures the Port should review to determine if they are appropriate include:

- Reposition ships within the harbor *(only for a distant source tsunami)*
- Removal of small boats or key assets from the inundation zone prior to tsunami wave arrival
- Removal of hazardous materials away from the inundation zone
- Removal of buoyant assets away from the inundation zone

These response measures will need to be reviewed to determine if they are appropriate for the Port, and if they should be undertaken for either a local or distant source tsunami, or for both. These response measures will require more time, research, and planning to be effective. Some measures may be determined by the Port to not be feasible, however creating the most robust and comprehensive response plans and processes that are feasible will help to reduce risk, save lives, and increase resiliency.

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

Please be sure to check out the appendices for additional information and other valuable resources that can be used to assist in developing and implementing tsunami maritime response and mitigation measures. These include:

- Detailed alerting information and information about the Vessel Traffic Service including channels and service area map
- Alerting response checklist for boaters
- Detailed tsunami alerting timeline and response roles
- Detailed explanation of modeling conducted for this strategy
- Stand-alone versions of all maps and graphics developed for this strategy
- The Whatcom County Tsunami Action Plan
- Evacuation Drill Guidance