Tsunami Maritime Response and Mitigation Strategy: The Port of Anacortes

Anacortes, Washington

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Prepared for:
The Port of Anacortes

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Section 1: An Introduction to Tsunamis

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

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

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

What are Tsunamis?

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

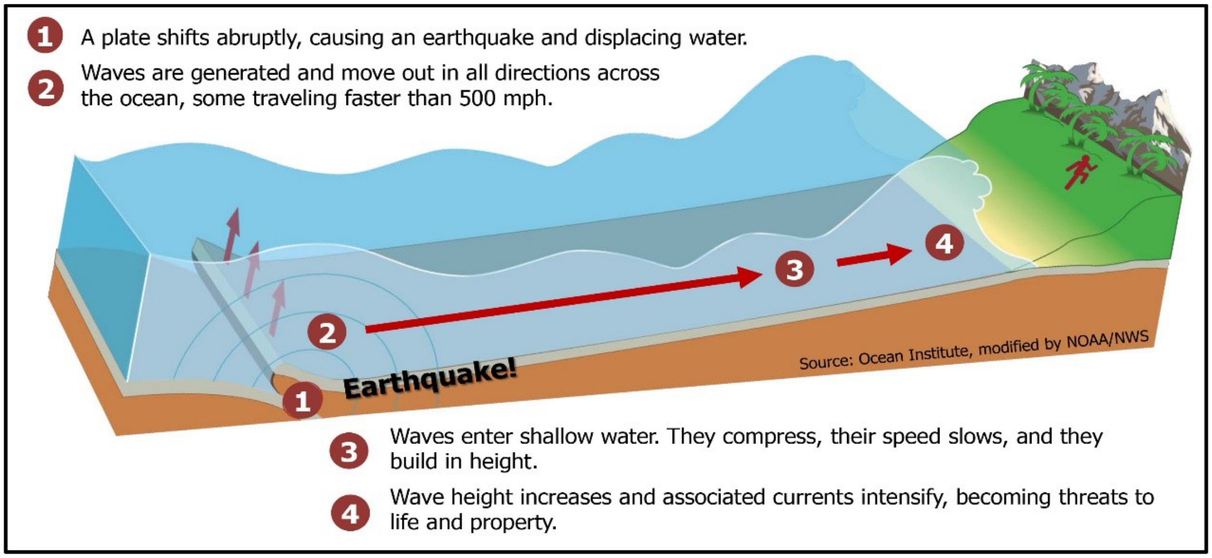

Figure 1: Earthquake generated tsunami diagram (Ocean Institute and NOAA/NWS).

Tsunamis triggered by earthquakes pose the greatest risk to Washington's coasts. The location of the earthquake plays a key role in determining the tsunami travel time to a coastal community, as well as its impact on the community. Washington is at risk from both local source and distant source tsunamis.

Local Source Tsunamis

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

Local source tsunamis are tsunamis for which the first waves arrive at a location in under 3 hours, and you will most likely feel shaking from the earthquake. These tsunamis are caused by large underwater earthquakes along the Cascadia Subduction Zone (CSZ) fault, upper plate crustal faults, and/or landslides. The risk from a local source tsunami tends to be very high due to the first waves arriving within minutes to a couple of hours. The waves can be 60+ feet high and the current speeds are very fast, which can cause significant damage to areas within the inundation zone. There is very little time for local authorities to respond and for people to evacuate to high ground.

An earthquake along the CSZ could produce catastrophic tsunami waves that hit the outer coast within 10-20 minutes in some locations. These waves would then hit low-lying parts of the northern inland waters and Puget Sound within two hours or more. Strong currents and water level changes would continue for 12-24 hours or longer. Additionally, earthquake shaking has the potential to cause slope failures, leading to landslide-induced tsunamis with no warning and immediate impacts. Aftershocks of sufficient size may also produce tsunamis in the days, weeks, and months following a major CSZ earthquake.

Distant Source Tsunamis

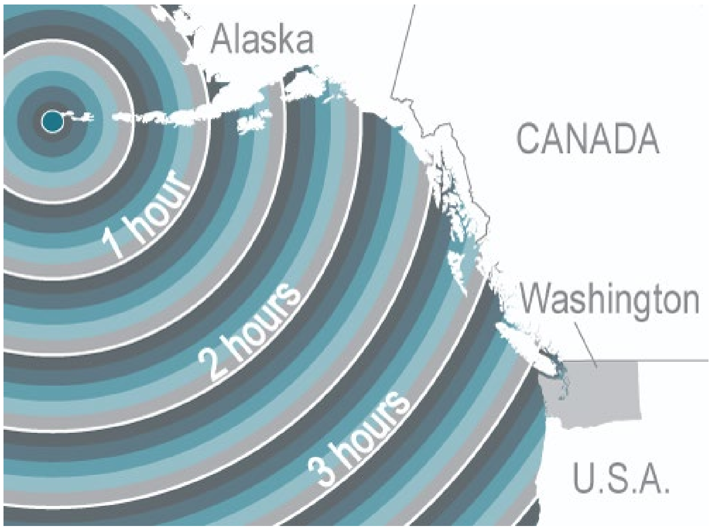

Figure 3: The wave arrival times of a distant tsunami originating off the coast of Alaska. (WA Geological Survey 2021)

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

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

Natural Tsunami Warning Signs

For both local and distant source tsunamis, there is always the possibility that you may not receive an official tsunami alert. You therefore need to be able to recognize the natural warning signs of a tsunami and respond immediately when you experience any one of them:

- If you are ONSHORE, you might:
    - Feel strong ground shaking (local source tsunami only)
    - Hear a loud roar from the ocean
    - See water rapidly receding, possibly exposing the sea floor
    - See water surging towards the shore faster than any tide

- If you are OFFSHORE on a vessel, you might:
    - Feel shaking through the hull of your vessel (local source tsunami only)
    - See a rapid or extreme shift in currents and simultaneous changes in wind wave heights

Official Tsunami Alerts

Tsunami alerts for Washington State originate from the National Oceanic and Atmospheric Administration's (NOAA) National Tsunami Warning Center (NTWC) in Palmer, Alaska. NTWC detects, locates, sizes, and analyzes earthquakes throughout the world 24 hours a day. NOAA is the authorized agency solely responsible for determining a region's appropriate tsunami alert level based on historical and preliminary earthquake event data, as well as preparing and issuing tsunami bulletins in which the alert level information is included. Tsunami alerts and event information for WA are disseminated by the National Tsunami Warning Center (NTWC), National Weather Service (NWS), United States Coast Guard (USCG), Federal Emergency Management Agency (FEMA), Washington State Emergency Operation Center (SEOC), Tribes, and local jurisdictions. Figure 4 shows a summary diagram of how tsunami alert dissemination works. Tsunami alerts require immediate response due to the urgent nature of the event so the more alert methods you are signed up for, the better your chance of receiving a tsunami alert in a timely manner.

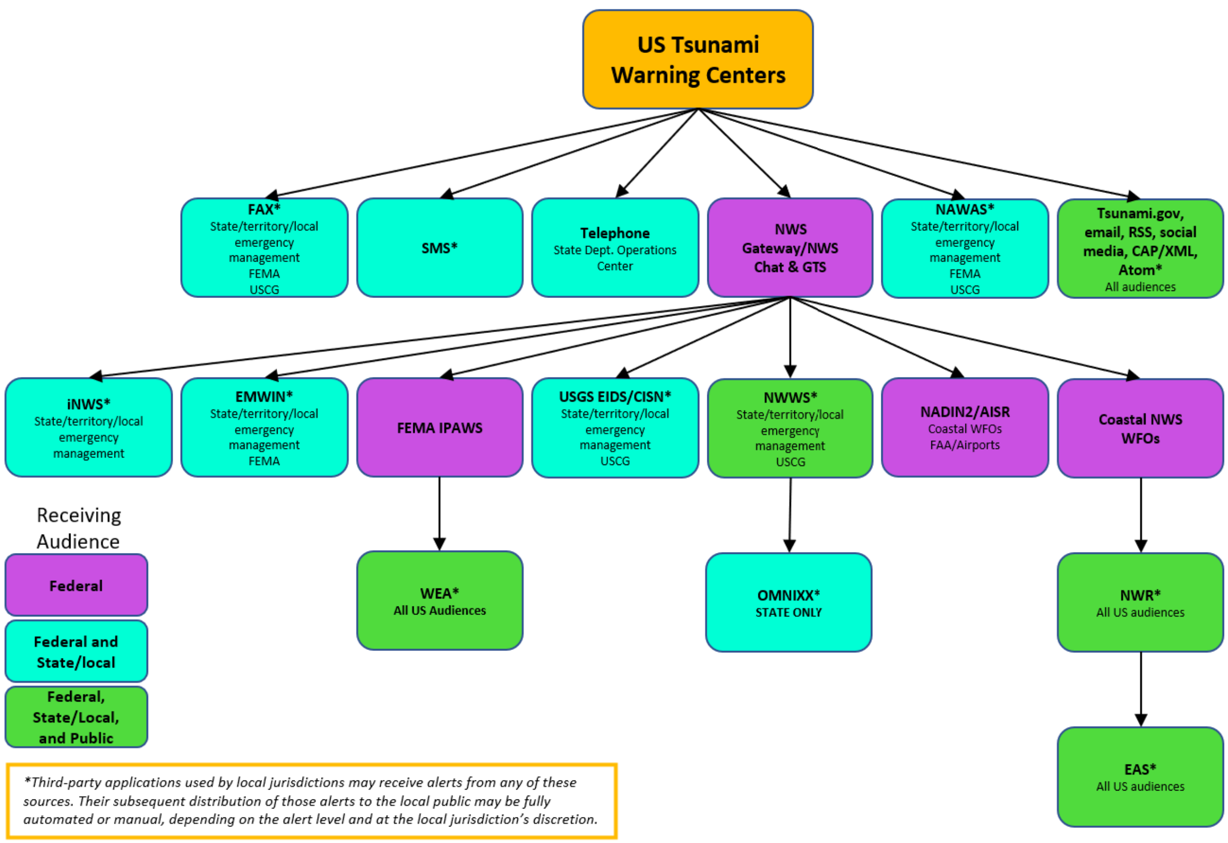

Figure 4: Diagram of tsunami alert dissemination (WA EMD 2023).

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

Tsunami Alert Messages

NTWC issues tsunami warnings, advisories, watches, and information statements. Each has a distinct meaning relating to recommended protective actions and local emergency response as summarized in Figure 5.

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 Statement	➡	Minor waves at most	➡	No action suggested

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

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

Tsunami Warning

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

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

Tsunami Advisory

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

Tsunami Watch

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

Tsunami Information Statement

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

Receiving Tsunami Alerts

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

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

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

Section 2: Tsunami Maritime Hazards

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

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

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

Tsunami Hazards for Mariners and Vessels

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

Tsunamis pose many significant hazards for boaters and their vessels and drag massive amounts of dangerous debris into the water (Figure 9). Sudden large fluctuations in water level can cause unprepared and unaware vessels to be quickly swamped with water and/or washed onto the shore. In shallow areas these fluctuations can also ground vessels on the sea floor when water rapidly recedes, only to be overtopped by water when the next wave rapidly arrives (Figure 6). These incoming and receding surges of water can also create large tsunami bores which are powerful surges of water, resembling a wall, that move upstream in rivers and estuaries during a tsunami. Tsunami bores can capsize boats, and complex coastal waves that pose a danger to navigation (Figure 7).

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

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

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

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

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

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

All the above risks also exist inside harbor and port areas. The extreme water level fluctuations during a tsunami have the potential for docks to overtop pilings, become detached from the shore or sea floor, or break apart in sections (Figure 10). Vessels can be grounded when water recedes, leaving them vulnerable to incoming waves. Large, deep keeled vessels can experience strong enough drag to rip them from their moorings or lift them on top of docks or the shore (Figure 11). Narrow entrances to harbors can amplify current speeds and cause water to move in unexpected directions. The confined nature and amount of infrastructure and vessels in harbors can lead to a massive amount of debris moving through the area, creating dangerous conditions. All these hazards can exist for 12-24 hours or more.

Summary of Tsunami Hazards that can Directly Affect Marine Vessels

- Severe water-level fluctuations
  - Docks 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 boaters who take their vessels offshore

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

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

Figure 12: Current velocity and associated damage.

Tsunami damage inside harbors can be directly attributed to strong currents. These currents are in excess of existing or 'normal' currents in the area, meaning their speed is added on top of the base, or normal tidal current speed. Damage varies based on the current speed and direction, as well as the age and location of docks and vessels, yet some generalities about the relationship between tsunami currents and damage can be noted (Figure 12).

One such generality is that the faster the current speeds the greater the chance and severity of damage. Beginning at ~3 knots (1 knot = 1.15 miles per hour) there is risk of minor to moderate damage to docks and smaller boats. Beginning at ~6 knots the risk increases to moderate to major damage and could impact larger vessels. Once current speeds reach ~9 knots or greater the risk of complete destruction becomes extreme to all maritime infrastructure and vessels. It should be noted that the 3-6-9 knot current speed thresholds are appropriate for newer (<30-40 years old) and well-maintained docks and harbor infrastructure. For estimating damage to older (>40-50 years old) and less maintained docks, it may be more appropriate to use current speed thresholds of 2-5-7 knots (Pat Lynett, 2014).

Actionable Tsunami Alert Levels

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

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

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

Tsunami Warnings	Tsunami Advisories
Tsunami wave heights could exceed 3 feet in harbors near the open coast, indicating very strong, dangerous currents and inundation of dry land is anticipated.	Peak tsunami wave heights of 1 to 3 feet are expected, indicating strong and dangerous currents may be produced in harbors near the open coast.
SIGNIFICANT tsunami currents or damage are possible to all maritime infrastructure and vessels.	SIGNIFICANT tsunami currents or damage to maritime infrastructure and vessels are possible near harbor entrances or narrow constrictions.

Actionable Natural Warning Signs for Tsunamis

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

- **Onshore**
    - Strong and/or long ground shaking (*only for local tsunamis*)
    - Loud roar from the ocean
    - Water rapidly receding, possibly exposing the sea floor
    - Wall of water surging towards shore faster than any tide
- **Offshore**
    - You may feel the earthquake through the hull of your vessel (*only for local tsunamis*)
    - You may see a rapid or extreme shift in currents and simultaneous changes in wind wave heights

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

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

Tsunami Warning or Natural Warning Signs

During the tsunami

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

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

If you are on the water but near shore:

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

If you are on the water and not near the shore:

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

Tsunami Warning or Natural Warning Signs	• At 100 fathoms (600ft) or deeper: If you are already at a location where the water depth is 100 fathoms or deeper, you are relatively safe from tsunamis. After the tsunami • If you are at an onshore assembly area, check with local authorities for guidance before returning to the inundation zone. • Do not return to local ports until you have firm guidance from the USCG and local authorities. • Local ports could sustain heavy damage from a local tsunami and may not be safe for days, weeks or months. • If at sea, check to see if you can reach an undamaged port with your current fuel supply and watch for floating debris or survivors that may have been washed out on debris. • If at sea, consider checking with the USCG about your role in response and recovery.

Lessons Learned in Alaska from the March 28, 1964 Alaska Tsunami

The first wave is not always the largest for tsunamis. At Kodiak, Alaska during the 1964 tsunami the first wave was 3.4 m (11 ft) at the nearby Naval Air Station, while the fifth wave was 7.6 m (25 ft) at high tide (Lander, 1996). The tsunami arrived within 10 minutes of the earthquake.

The primary lesson was that there was INSUFFICIENT time for harbor personnel or vessel captains/owners to do any response actions (i.e., remove vessels offshore or out of the harbor) prior to the arrival of the tsunami. Evacuation inland to high ground out of the tsunami inundation zone was the only possible action.

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

Tsunami Advisories	**During the tsunami** • 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 tsunami** • Port authorities will not allow public to reenter structures and vessels in the water until advisory is cancelled and conditions are safe.

Tsunami Warnings	**During the tsunami**
	• 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:
	    o 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.
	    o 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.
	    o It is not recommended that captains take their vessels offshore during a tsunami because they could put themselves at greater risk of injury. However, if they do decide to go offshore, they should have the experience, fuel, and supplies to stay offshore for more than 24 hours or possibly have the resources to travel to a different port if extensive damage occurs to their home port.

Tsunami Warnings

- If conditions do not permit, dock your boat and head for inland to high ground.
- For the OUTER COAST ONLY, VESSELS considering leaving the harbor and heading to sea, should consider the following:
  - Make sure your family is safe first
  - Check tide, bar, and ocean conditions
  - Check the weather forecast for the next couple of days
  - Ensure you have enough fuel, food, and water to last multiple days at sea
  - If you do not have time to accomplish your goal, you should not make the attempt.
  - 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; then exit the tsunami inundation zone.

After the tsunami

- 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.

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

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

Prior to the arrival of the March 11, 2011 Japanese tsunami in Crescent City, California, many commercial fishing boats headed to sea. Once the tsunami hit and they realized they were unable to return to Crescent City Harbor due to its damage, decisions had to be made as to where to go because of a huge storm approaching the coast. Some vessels had enough fuel to make it to Brookings Harbor in Oregon or to Humboldt Bay, California. Some smaller vessels did not have enough fuel and made the choice to re-enter Crescent City Harbor to anchor. Some of the captains had never been to Humboldt Bay and some were running single-handed as they did not have enough time to round up crew. The captains kept in close contact with each other for safety and for moral support. Even though the tsunami initially impacted the west coast on the morning of March 11, 2011, the largest surges in Crescent City did not arrive until later in the evening, when the waves coincided with high tide.

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

Boater Considerations During Both Local and Distant Tsunamis

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

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

Within those considerations, it’s important to know: the distance to shore or deep water (100 fathoms or 600-foot depth); the skill level of the captain and crew; the vessel speed and capability; the draft of the vessel; the amount of provisions, fuel, and equipment on board; tide stage and conditions on the sea; and whether the vessel has adequate communication with other nearby vessels and authorities on shore, too (Figure 13).

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

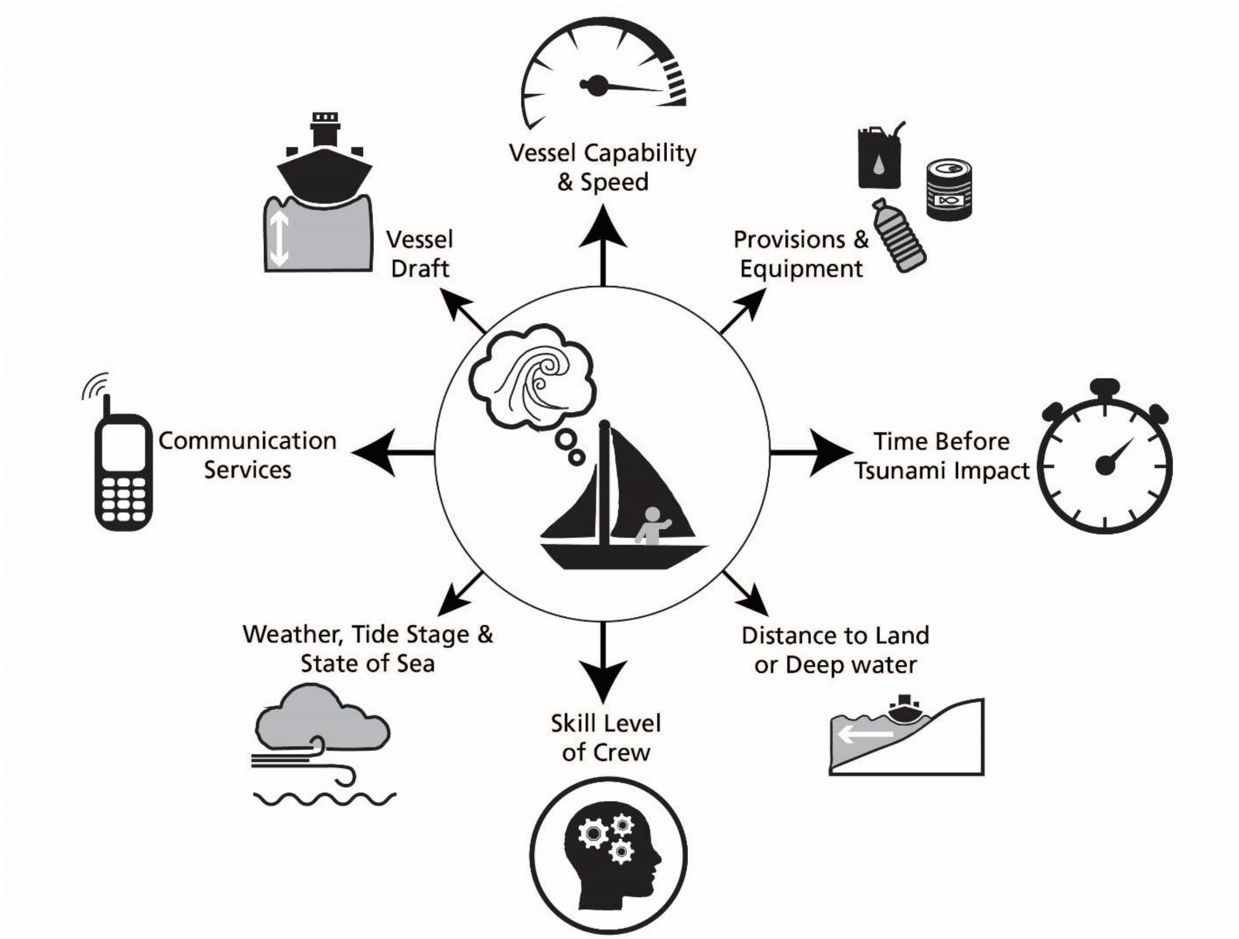

Figure 13: Considerations for boaters who are already offshore during a tsunami (WA Geological Survey).

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

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

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

The Port of Anacortes and the Guemes Channel

Located in Washington State’s scenic Skagit County, the Guemes Channel and Port of Anacortes area is a vibrant maritime community that boasts a thriving economy, bustling tourism industry, and impressive infrastructure. With its strategic location on the Guemes Channel, the Port serves as a vital hub for marine commerce and recreational activities.

The Port of Anacortes plays a pivotal role in supporting various economic industries. It operates several lines of business, including deep-water marine terminals and industrial properties. These facilities provide a crucial link between land and sea transportation, facilitating the movement of goods and cargo. In recent years, the Port has experienced significant growth, with a steady increase in ship and barge traffic. In 2022 alone, over 120 deep-water vessels called at the Port, highlighting its importance as a major maritime gateway.

The Guemes Channel and Port of Anacortes area also thrives on its flourishing tourism sector. The region's natural beauty, rich maritime history, and diverse recreational opportunities attract visitors from near and far. The pristine waters of the Guemes Channel beckon boaters, sailors, and kayakers, offering breathtaking vistas and serene sailing conditions. Additionally, the area's vibrant marine ecosystem lures nature enthusiasts and wildlife lovers, providing ample opportunities for whale watching, bird spotting, and exploring marine sanctuaries.

To cater to the needs of both residents and tourists, the maritime community boasts impressive infrastructure. The Port of Anacortes features a modern marina that accommodates a wide range of vessels, from recreational boats to commercial fishing vessels. The marina offers a multitude of amenities, including 750 recreational boat slips (smaller pleasure craft) and 250 commercial boat slips (upwards of 60 ft), parking facilities, well-maintained bathrooms and showers, vessel pump-out stations, and a boat launch ramp. Fuel docks and on-site seafood processing facilities cater to the needs of fishermen and seafood enthusiasts.

Beyond the Port-managed facilities, the Guemes Channel and Port of Anacortes area boasts additional attractions and infrastructure. The community is home to a variety of small businesses, including charming waterfront restaurants, boutique shops, and art galleries, providing a vibrant atmosphere for both locals and visitors. The US Army Corps of Engineers maintains multiple break waters and jetties, ensuring safe navigation and protecting the shoreline. Moreover, several privately leased fixed piers enhance the Port's capacity and diversify the available services.

The chosen study area for this Tsunami Maritime Strategy focuses on the Port of Anacortes, Cap Sante Marina and the Guemes Island Ferry Terminal encompassing these key sites within its scope for modeling purposes (as shown in Figure 14). This site-specific modeling, which considers factors such as topography, bathymetry, and coastal dynamics, is vital to the assessment of potential tsunami impacts on these critical maritime infrastructures. Through comprehensive analysis and simulation, the study aims to inform the development of effective mitigation measures, emergency response plans, and long-term strategies to safeguard the Port of Anacortes and its surrounding maritime community against the threat of tsunamis.

Study Overview

The tsunami modeling results presented in this Strategy are generated from two distinct seismic scenarios. The first scenario represents a local magnitude 9.0 earthquake along the full length of the Cascadia Subduction Zone (CSZ). This scenario is referred to as the CSZ “Extended L1” scenario (see *Dolcimascolo and others, 2021* for more information on this source). The second scenario represents a distant magnitude 9.2 earthquake along the Alaska-Aleutian Subduction Zone (AASZ). This distant scenario is similar in magnitude to the Great Alaskan earthquake that occurred on March 27, 1964, though the epicenter has been moved to maximize the tsunami impacts to Washington state (see Scenario One in *Chamberlin and others, 2009*). Both of these seismic scenarios generate substantial waves that travel into Washington’s inner waterways and reach the Guemes Channel. Refer to *Timing of Tsunami* for specific details on when tsunami effects impact this study area. Local land elevation changes within Guemes Channel from the earthquake deformation are not expected from these two scenarios as this location is far from the earthquake regions.

These modeled earthquake scenarios represent Washington’s “maximum considered” tsunami sources currently used in preparedness, mitigation, response, and recovery planning for a local CSZ event and a distant M 9.2 Alaska event. CSZ earthquakes occur every 300-600 years while Alaska averages a magnitude 8 or larger earthquake every 13 years.

For this Strategy, the Guemes Channel study area was divided into three regions, denoted as 1) Anacortes Ferry Terminal, 2) Guemes Island Ferry Terminal, and 3) Cap Sante Marina. Each of these regions contain model results for maximum onshore inundation (flooding) depths, maximum current speeds, and minimum offshore water depths for both earthquake scenarios. These models were generated on 1/9th arc-second elevation grids in both the longitude and latitude directions (approximately 8 ft and 10 ft, respectively). Additional overview figures covering the entire Guemes Channel also display tsunami modeling data on a 1/3rd arc-second elevation grid (approximately 23 ft and 33 ft in the longitude and latitude directions).

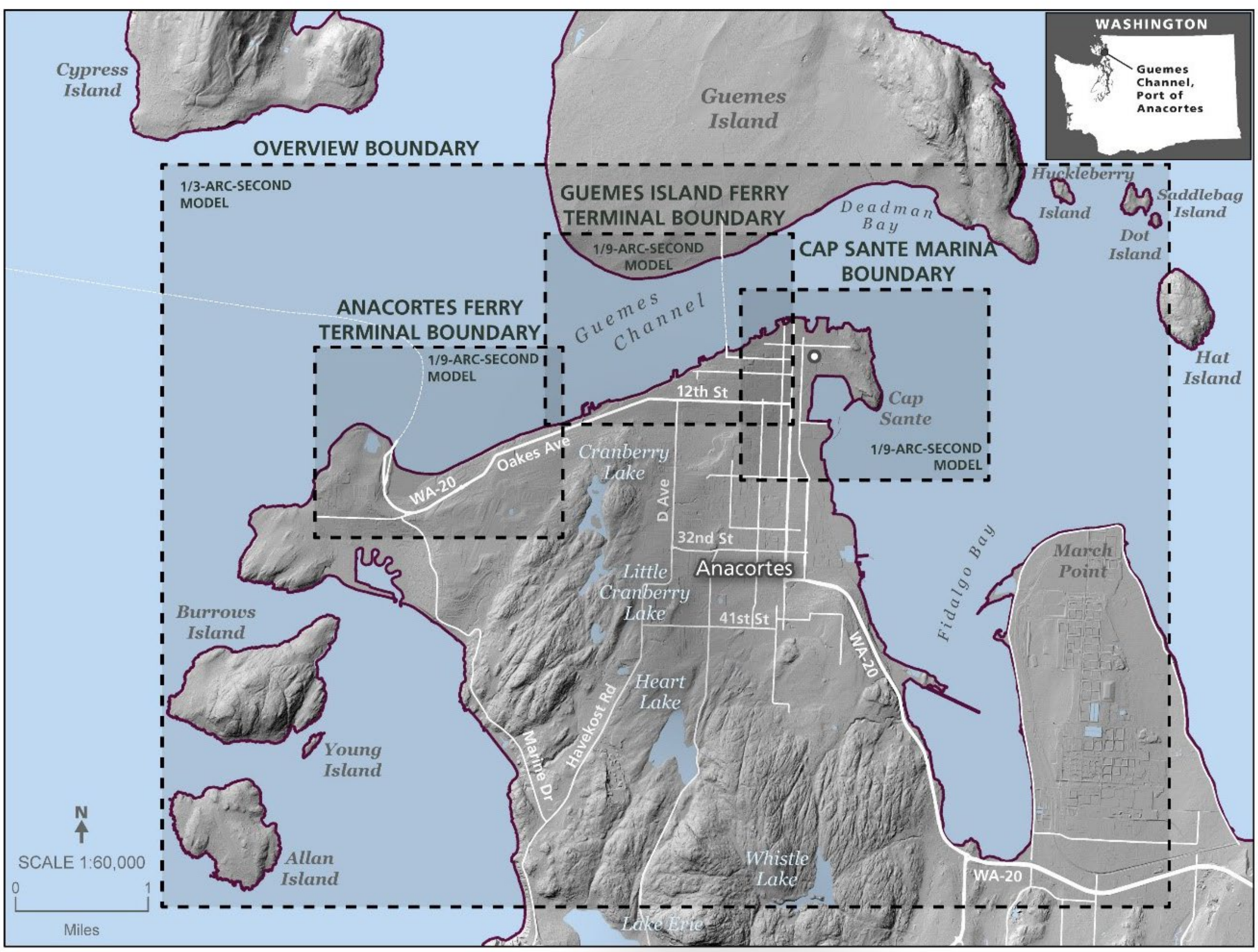

Figure 14: Study area for the Port of Anacortes Tsunami Maritime Response and Mitigation Strategy

Tsunami Risk Assessment for the Port of Anacortes and Guemes Channel

Cascadia Subduction Zone Tsunami

The onset of a Cascadia Subduction Zone (CSZ) earthquake triggers significant seismic activity, resulting in widespread damage to roads and infrastructure in the affected coastal region. As the ground shakes, roads sustain damage, with downed power lines and structural issues further complicating matters for emergency responders and community members.

Following the earthquake, the drawdown phase begins approximately 20 minutes later, causing the water to slowly recede from the Guemes Channel, reaching a depth of 1 foot after 50 minutes. As current speeds increase during this drawdown period, reaching up to 9 knots in many areas of the port, the risk of complete destruction of shoreline infrastructure becomes imminent. This phase of the tsunami poses a prolonged period of vulnerability for vessels navigating the Guemes Channel waterways, including the Guemes Channel Island Ferry and large moored vessels along the Port of Anacortes' Piers 1 and 2.

Approximately 1 hour and 45 minutes after the earthquake, a wave crest of at least 1 foot begins to arrive, initiating inundation along the waterfront and ferry terminals. The maximum wave crest occurs around 1 hour and 55 minutes after the earthquake, resulting in peak inundation depths and wave heights. Modeled tsunami inundation reaches about 5 feet or more over land, leading to far-reaching and severe implications for maritime infrastructure and road usability post-tsunami.

The extensive flooding poses significant risks to essential facilities and transportation networks along the waterfront, with significant consequences for maritime operations, emergency response capabilities, and community resilience. Maritime infrastructure such as docks, piers, and marinas would be subjected to considerable damage and destruction, as the force of the tsunami waves surpasses the capacity of existing structures to withstand inundation. Overtopping of pilings and structural collapse could lead to the loss of critical assets, disruption of vessel operations, and safety hazards for personnel navigating the affected areas.

Furthermore, the inundation of roads and transportation networks would result in widespread flooding and obstruction of access routes, potentially hindering emergency response efforts and evacuation procedures along key roads, despite lead time prior to wave arrival. The damage to essential infrastructure could have cascading effects on the local economy, public safety, and community well-being, underscoring the urgent need for comprehensive risk mitigation strategies and infrastructure resilience measures.

With current speeds well exceeding 9 knots in many areas of the port during wave arrival, widespread destruction to the majority of maritime infrastructure and vessels is imminent. Large boats are at risk of being ripped from their moorings, including the probable collapse of critical infrastructure such as the pilings supporting the administration offices of the Port buildings on the Guemes Channel.

As the tsunami waves inundate the coastline, the dangerous conditions persist, with vessels and infrastructure subjected to the relentless force of the waves. The dynamic nature of the tsunami event, combined with the drawdown effects and seismic activity, underscores the urgent need for proactive planning, investment in resilient infrastructure, and coordinated emergency response efforts.

Alaskan Aleutian Subduction Zone Tsunami

In the aftermath of an Alaska-Aleutian Subduction Zone (AASZ) scenario, the maritime infrastructure faces a unique array of challenges and risks. Unlike the Cascadia Subduction Zone (CSZ) scenario, which induces significant seismic activity and widespread damage, the AASZ scenario presents a different profile of inundation, current dynamics, and no localized earthquake shaking.

With inundation depths averaging around 2 feet, the impact on maritime infrastructure is less severe compared to the CSZ scenario. However, this doesn't imply a lack of risk. Shoreline infrastructure, particularly in areas adjacent to the Guemes Channel and Cap Sante Marina, remains vulnerable to damage. Despite the relatively lower inundation depths, the potential for damage to essential facilities such as docks, piers, and marinas persists, especially in areas where currents reach speeds of up to 9 knots.

The variability in current speeds poses a significant challenge for maritime operations. While currents may be lower in some areas, reaching speeds of 3-6 knots above average, there are pockets within the Guemes Channel and Cap Sante Marina where speeds exceed 9 knots. Such high-speed currents can exert immense force on maritime infrastructure, increasing the risk of structural damage and vessel displacement.

Regarding the wave arrival times, the AASZ scenario unfolds in a manner that allows for more meticulous attention to timing and preparedness, arming emergency managers and responders with valuable time to initiate lifesaving response actions. Approximately 5 hours later, the first wave arrives at a crest, marking the beginning of inundation along the waterfront and ferry terminals. However, the wave heights are variable, with subsequent waves potentially exceeding the initial wave in size. These waves have the potential to overtop pilings and cause significant damage in Cap Sante Marina.

Furthermore, the largest drawdown occurs much later in the tsunami event, emphasizing the prolonged duration of high-risk conditions along the coastline. With the drawdown phase commencing at about 5 hours and 50 minutes, vessels navigating the Guemes Channel and Cap Sante Marina face the risk of bottoming out and being pulled from cleats and moorings as currents increase. This underscores the critical need for proactive planning, timely evacuation procedures, and infrastructure resilience measures to mitigate the potential impacts of tsunamis originating from the Alaska-Aleutian Subduction Zone.

Tsunami Inundation Results

Tsunami inundation (tsunami-induced flooding over previously dry land) poses a risk to any infrastructure built on low-lying land along the waterfront and ferry terminals within the Guemes Channel. The following figures in this section (Figures 15-18) depict both modeled tsunami inundation extent (how far inland) and the depth of flooding from each simulated tsunami scenario if the tsunami arrived at mean high water (providing the most conservative results).

For the CSZ earthquake scenario, the Port of Anacortes shows some inundation north of 3rd Street for the area west of Q Avenue and just north of 4th Street for the area east of Q Avenue. Cap Sante Marina also experiences inundation in many areas, extending west beyond Q Avenue and north along Market Street, coalescing with the inundation north of 4th Street. Shoreline infrastructure, such as Lovric's Marina, the Anacortes Ferry terminals, Trident Seafoods (north of L Avenue), and Curtis Wharf (north of O Avenue), is also prone to modeled inundation. Overall inundation depths vary and are dependent on the local topography, though on average these depths are less than 5 feet at Port facilities. In the AASZ scenario, modeled tsunami inundation is minimal, with exception to the immediate shoreline and the low-lying area east of the Anacortes Ferry Terminal. This scenario shows average flooding depths of 2 feet or less.

Overview: Cascadia Subduction Zone scenario

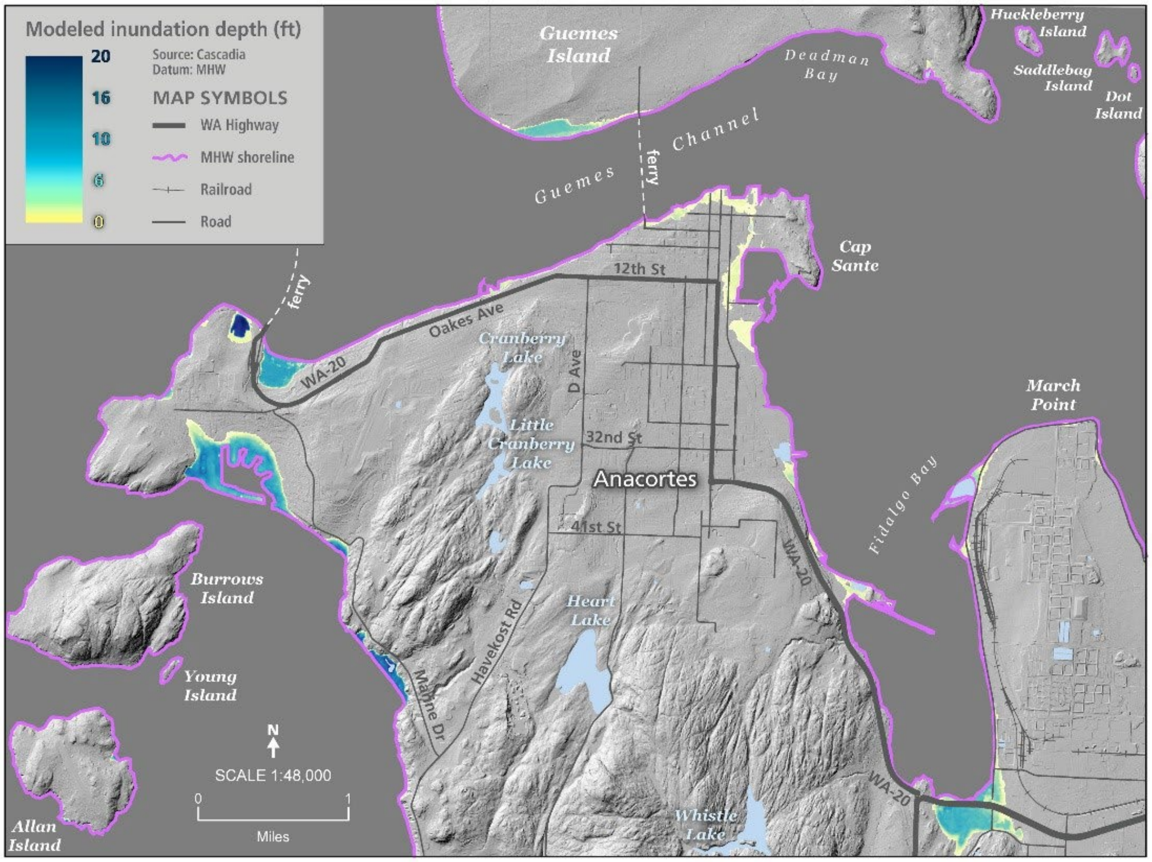

Figure 15: Overview of modeled tsunami inundation flooding depths over land from the Cascadia subduction zone earthquake scenario. Tidal datum: mean high water. Model resolution: 1/3rd arc-second (10m).

Overview: Alaska-Aleutian Subduction Zone scenario

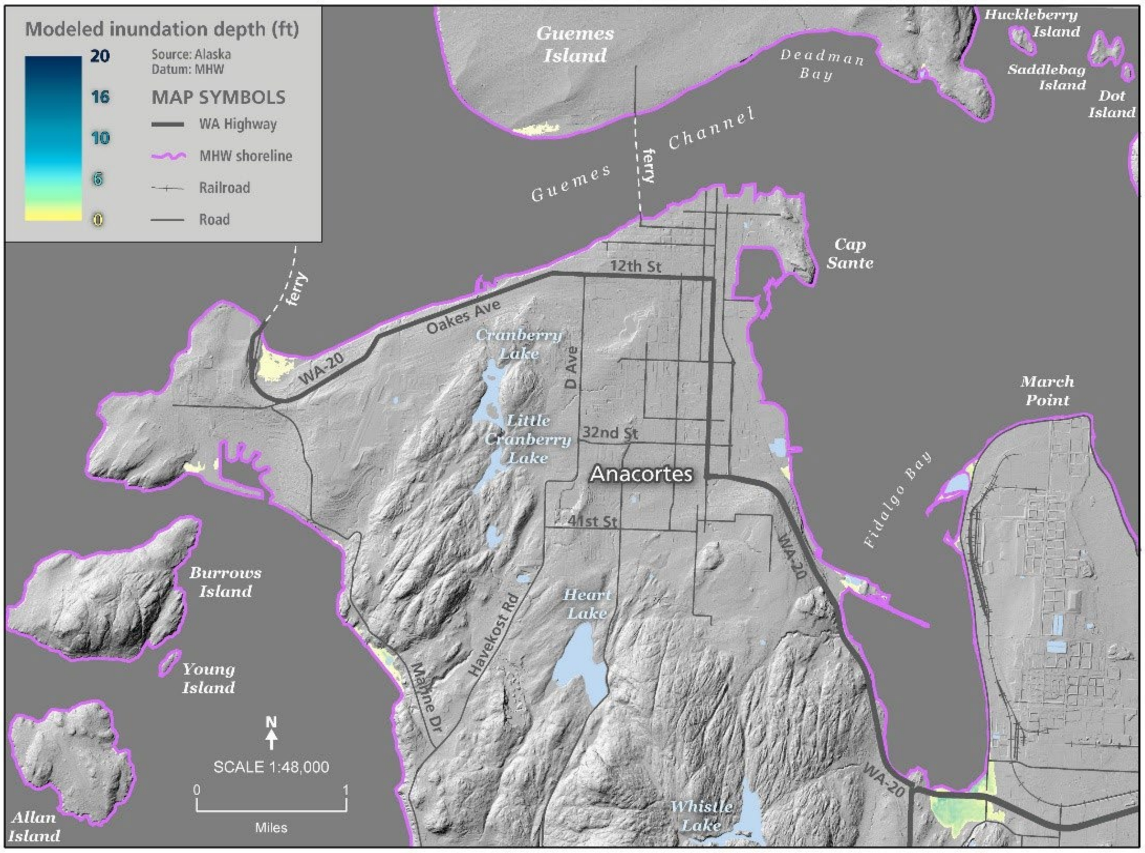

Figure 16: Overview of modeled tsunami inundation flooding depths over land from the Alaska-Aleutian subduction zone earthquake scenario. Tidal datum: mean high water. Model resolution: 1/3rd arc-second (10m).

Guemes Island Ferry Terminal: Cascadia Subduction Zone scenario

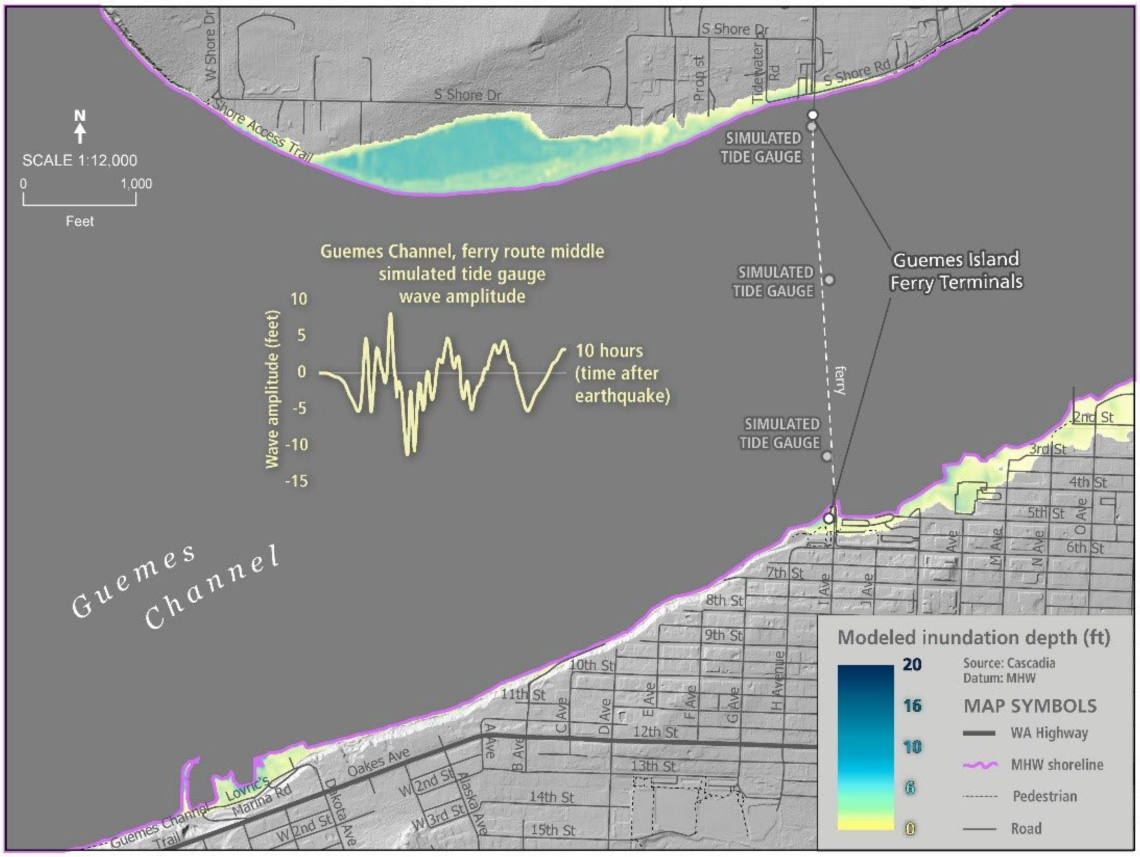

Figure 17: Modeled tsunami inundation flooding depths over land at the Guemes Island Ferry Terminal from the Cascadia subduction zone earthquake scenario. Tidal datum: mean high water. Model resolution: 1/9th arc-second (3m).

Cap Sante Marina: Cascadia Subduction Zone scenario

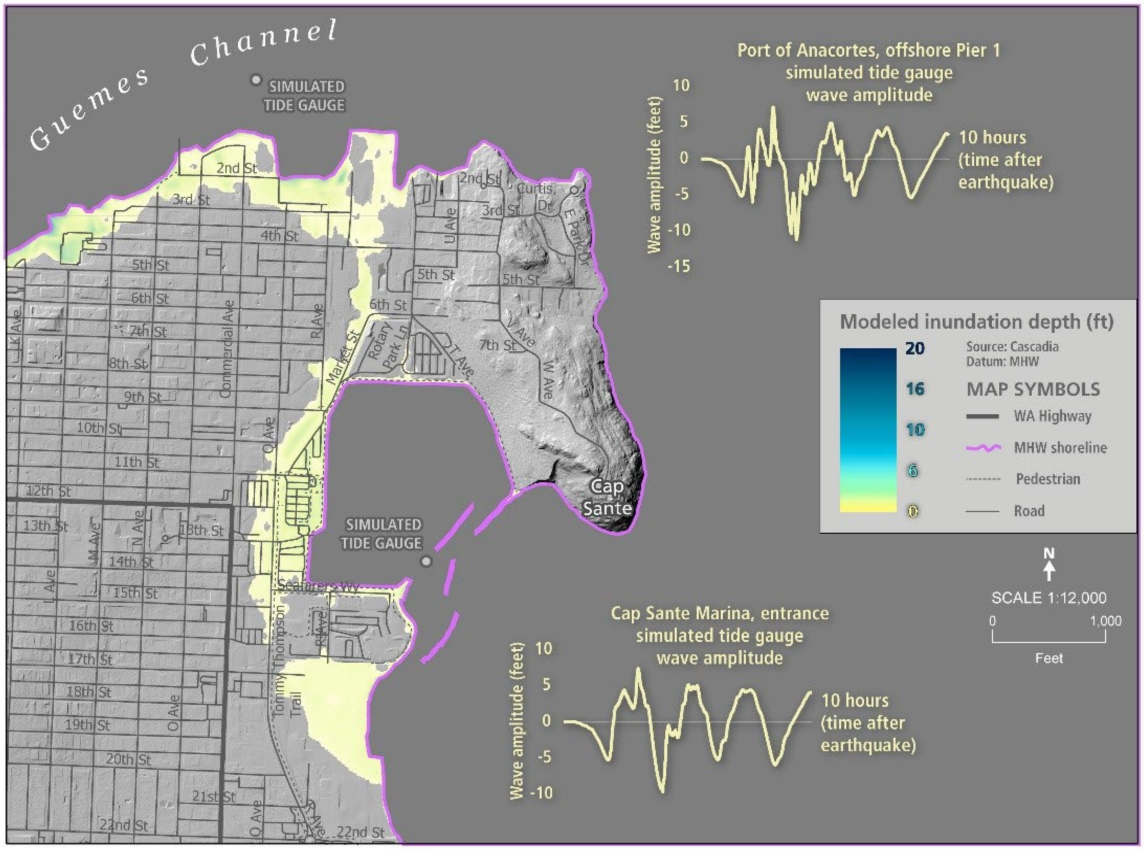

Figure 18: Modeled tsunami inundation flooding depths over land at Cap Sante Marina from the Cascadia subduction zone earthquake scenario. Tidal datum: mean high water. Model resolution: 1/9th arc-second (3 m).

Tsunami Current Speed Results

This section depicts the maximum modeled tsunami current speeds (in knots) at any given time within Guemes Channel from each tsunami scenario (a knot is equal to 1 nautical mile or ~1.15 land mi/hr). All modeled current speeds were generated on static tides, meaning normal day-to-day currents are not included in the modeling and should be factored into the reported speeds. The following figures (Figures 19-24) show speeds binned into four ranges, all on top of the normal current speeds for the location: 0–3 knots, 3–6 knots, 6–9 knots, and >9 knots, which follow the port damage categorization of Lynett and others (2014) that approximates hazards to ships and docking facilities. Speeds ranging from 0-3 knots represent no expected damage, 3-6 knots represent minor/moderate damage possible, speeds of 6-9 knots represent major damage possible, and speeds greater than 9 knots represent extreme damage possible.

Modeled tsunami current speeds locally exceed 9 knots, the maximum categorization, from both seismic scenarios along the center of the Guemes Channel, and specifically crossing the Guemes

Island ferry route. Certain topographic features contribute to these increased currents and have the potential to form vortices. Examples of these features include entrances into harbors and marinas, like at the entrance to Cap Sante Marina, and around small islands or land spits with narrow passageways. In general, narrower waterway channels and nearshore locations where normal currents and tide interactions are the greatest are also likely to have the most significant tsunami currents. Additionally, the fastest speeds were sometimes captured during the trough phase of the tsunami when water gets pulled away from shore. This is especially the case east of Cap Sante, among elsewhere in the channel, where the fastest speeds appear to converge in 'finger-like' patterns pointing in opposite directions.

It is important to recognize that any modeled regions subject to high current speeds may actually be much more widespread than what is shown in the figures. This is due to the sensitivity of current speeds in the tsunami modeling—small tweaks in the model setup cause vortices to take slightly different paths. Because of this sensitivity, the speeds on each figure represent the maximum values generated when simulating the tsunami at either mean high water or mean low water together. The spatial extents of these high-speed zones are thus only estimates and mariners should avoid these general areas during a tsunami.

Figures 25-30 show modeled tsunami current speed over time at various synthetic tide gauges comparing both the Cascadia and Alaska-Aleutian subduction zone earthquake scenarios, respectively. All reported speeds are maximum values generated from either the mean high water or mean low water simulations.

Overview: Cascadia Subduction Zone scenario

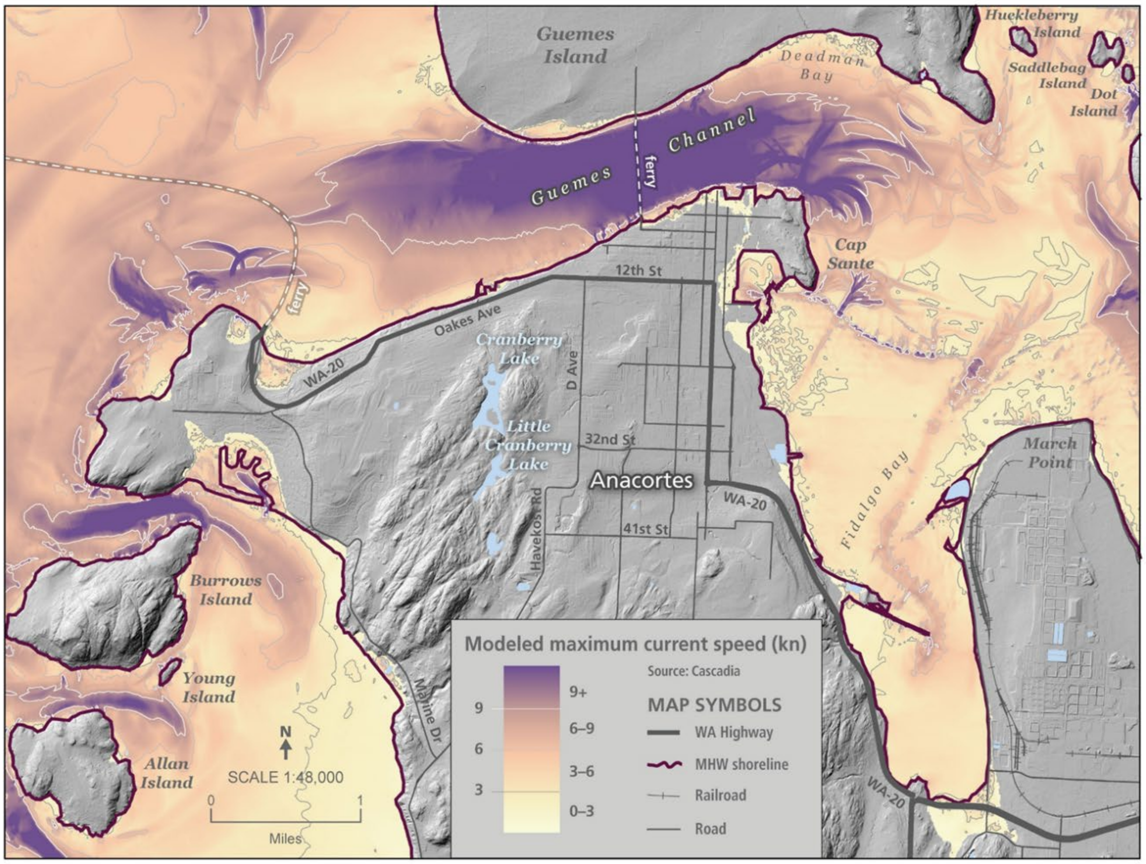

Figure 19: Overview of modeled tsunami current speeds from the Cascadia subduction zone earthquake scenario. Tidal datum: maximum values generated between the mean high water and mean low water runs. Model resolution: 1/3rd arc-second (10 m).

Overview: Alaska-Aleutian Subduction Zone scenario

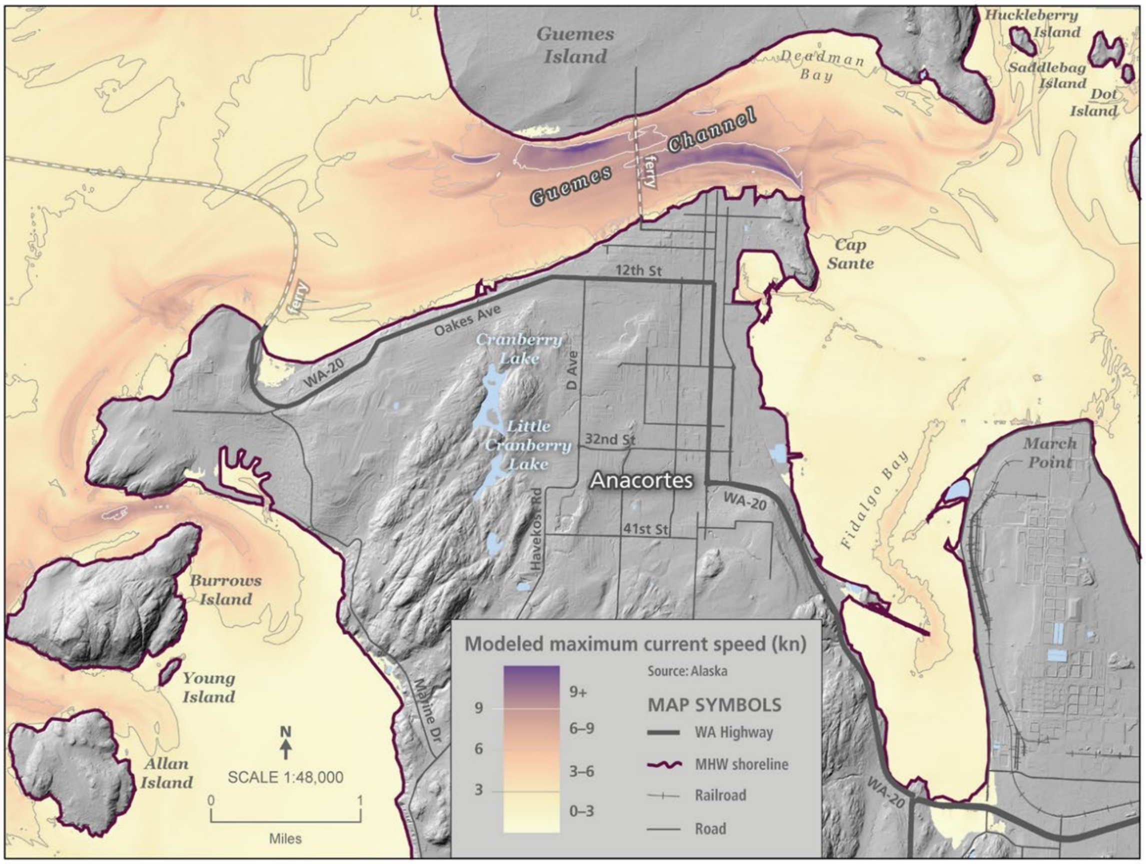

Figure 20: Overview of modeled tsunami current speeds from the Alaska-Aleutian subduction zone earthquake scenario. Tidal datum: maximum values generated between the mean high water and mean low water runs. Model resolution: 1/3rd arc-second (10 m).

Cap Sante Marina: Cascadia Subduction Zone scenario

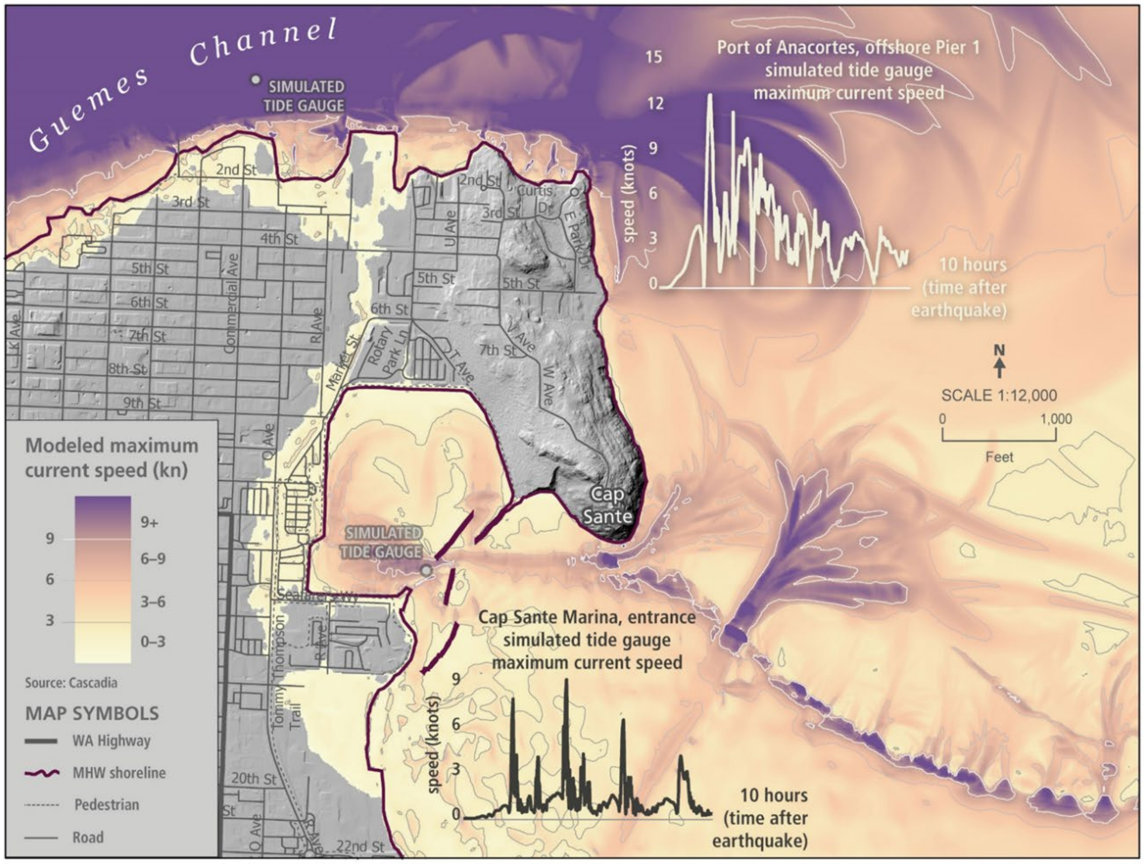

Figure 21: Modeled tsunami current speeds at Cap Sante Marina from the Cascadia subduction zone earthquake scenario. Tidal datum: maximum values generated between the mean high water and mean low water runs. Model resolution: 1/9th arc-second (3 m).

Cap Sante Marina: Alaska-Aleutian Subduction Zone scenario

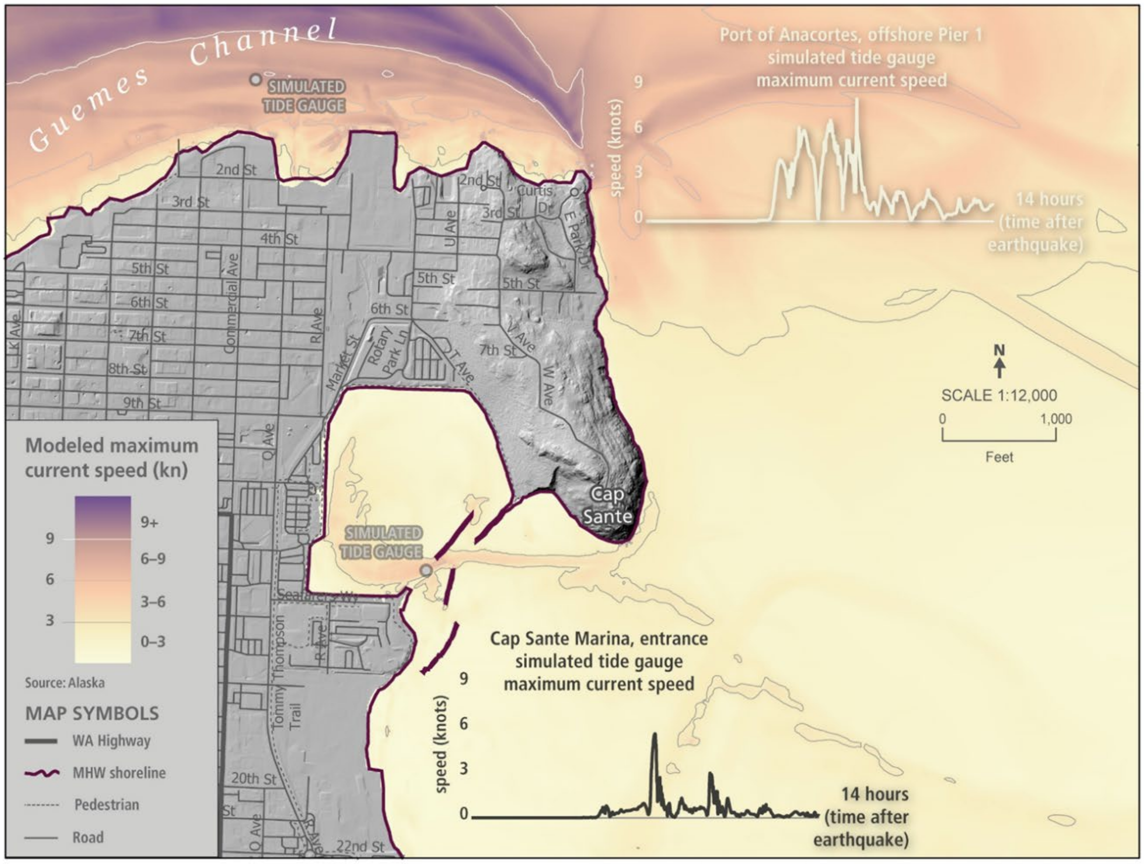

Figure 22: Modeled tsunami current speeds at Cap Sante Marina from the Alaska-Aleutian subduction zone earthquake scenario. Tidal datum: maximum values generated between the mean high water and mean low water runs. Model resolution: 1/9th arc-second (3 m).

Guemes Island Ferry Terminal: Cascadia Subduction Zone scenario

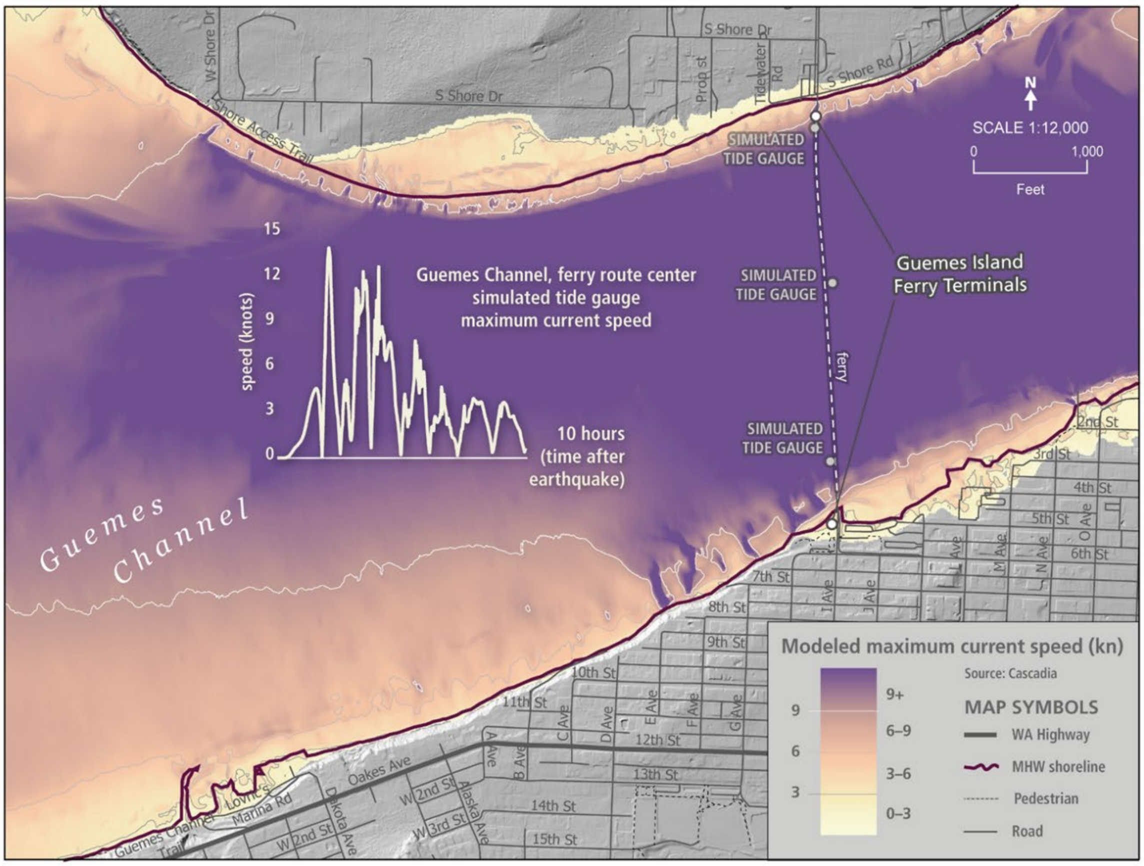

Figure 23: Modeled tsunami current speeds at the Guemes Island Ferry Terminal from the Cascadia subduction zone earthquake scenario. Tidal datum: maximum values generated between the mean high water and mean low water runs. Model resolution: 1/9th arc-second (3 m).

Guemes Island Ferry Terminal: Alaska-Aleutian Subduction Zone scenario

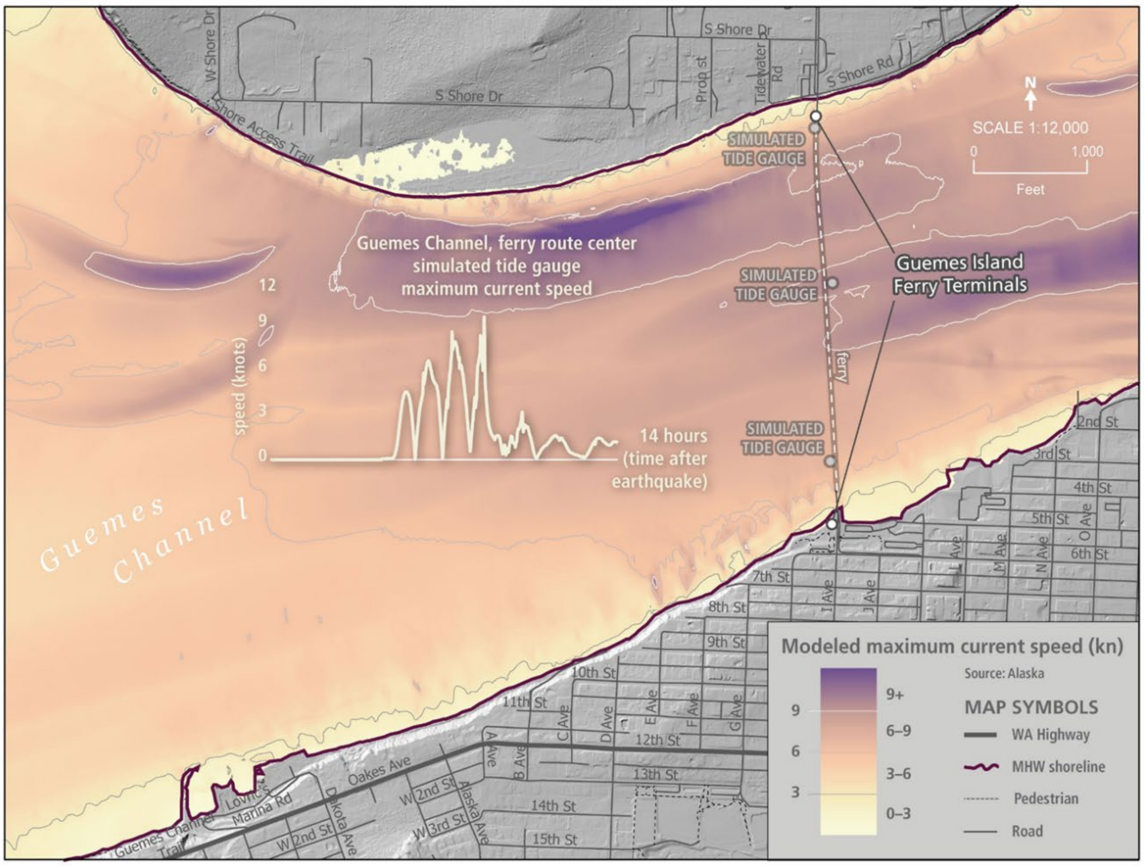

Figure 24: Modeled tsunami current speeds at the Guemes Island Ferry Terminal from the Alaska-Aleutian subduction zone earthquake scenario. Tidal datum: maximum values generated between the mean high water and mean low water runs. Model resolution: 1/9th arc-second (3 m).

Anacortes Ferry Terminal: Current speeds

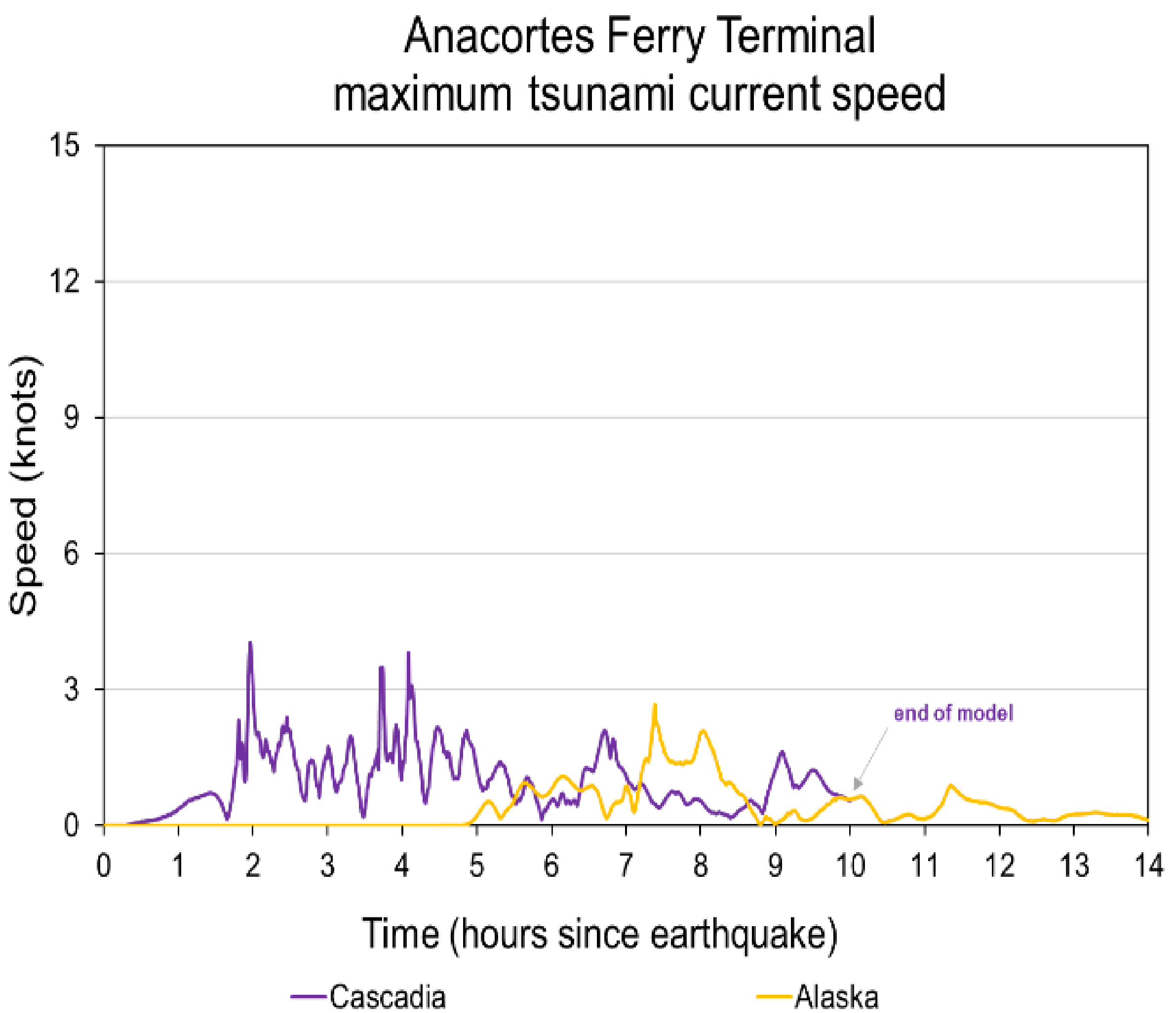

Figure 25: Modeled tsunami current speed over time at the Anacortes Ferry Terminal synthetic tide gauge. Location: Latitude 48.50754547, Longitude -122.6773682. Purple and yellow lines represent simulations from the Cascadia and Alaska-Aleutian subduction zone earthquake scenarios, respectively. Reported speeds are maximum values generated from either the mean high water or mean low water simulations.

Guemes Island Ferry Terminal, Fidalgo: Current speeds

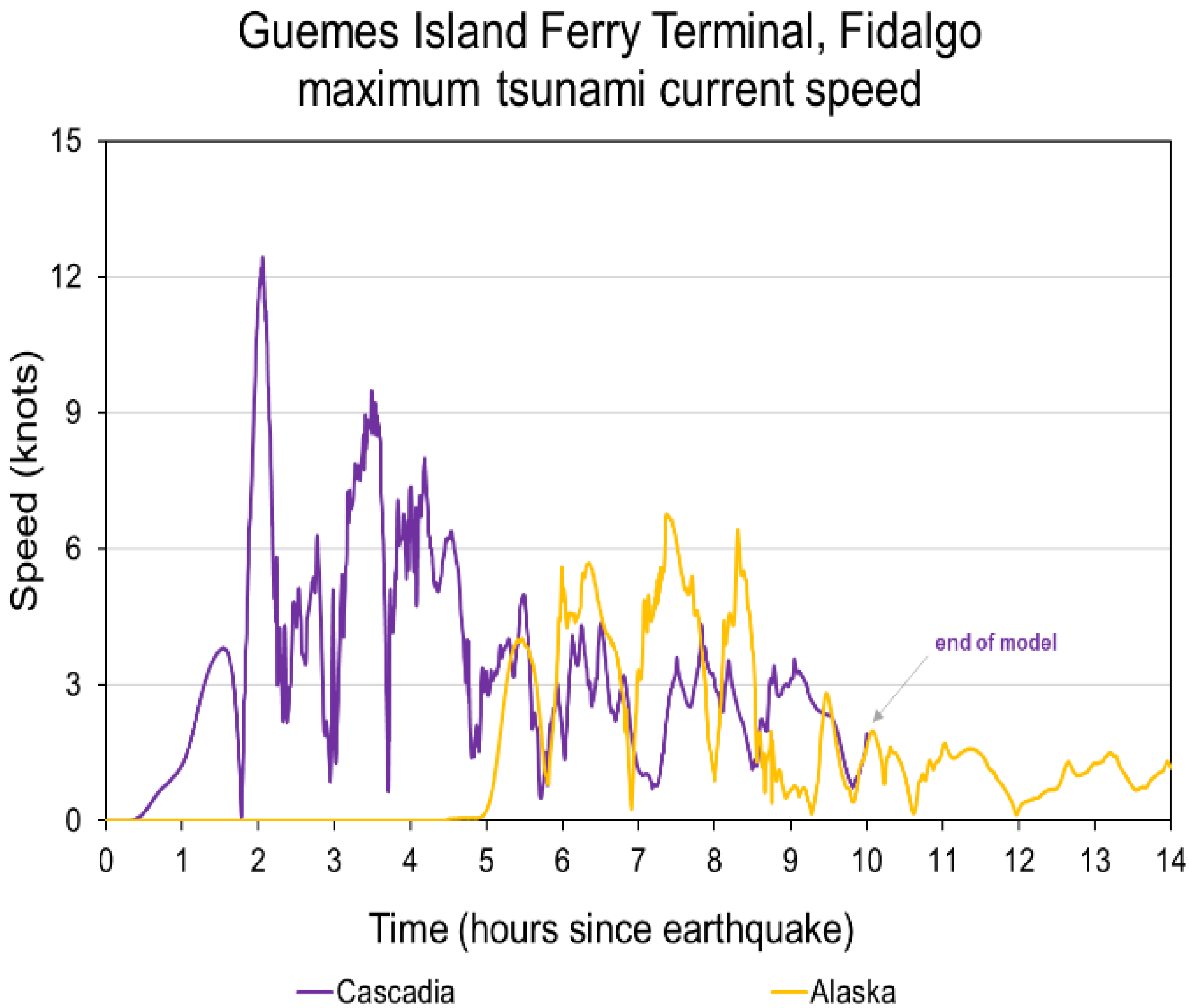

Figure 26: Modeled tsunami current speed over time at the Guemes Island Ferry Terminal synthetic tide gauge on the Fidalgo Island side. Location: Latitude 48.51976776, Longitude -122.6238400. Purple and yellow lines represent simulations from the Cascadia and Alaska-Aleutian subduction zone earthquake scenarios, respectively. Reported speeds are maximum values generated from either the mean high water or mean low water simulations.

Guemes Island Ferry Terminal, Guemes: Current speeds

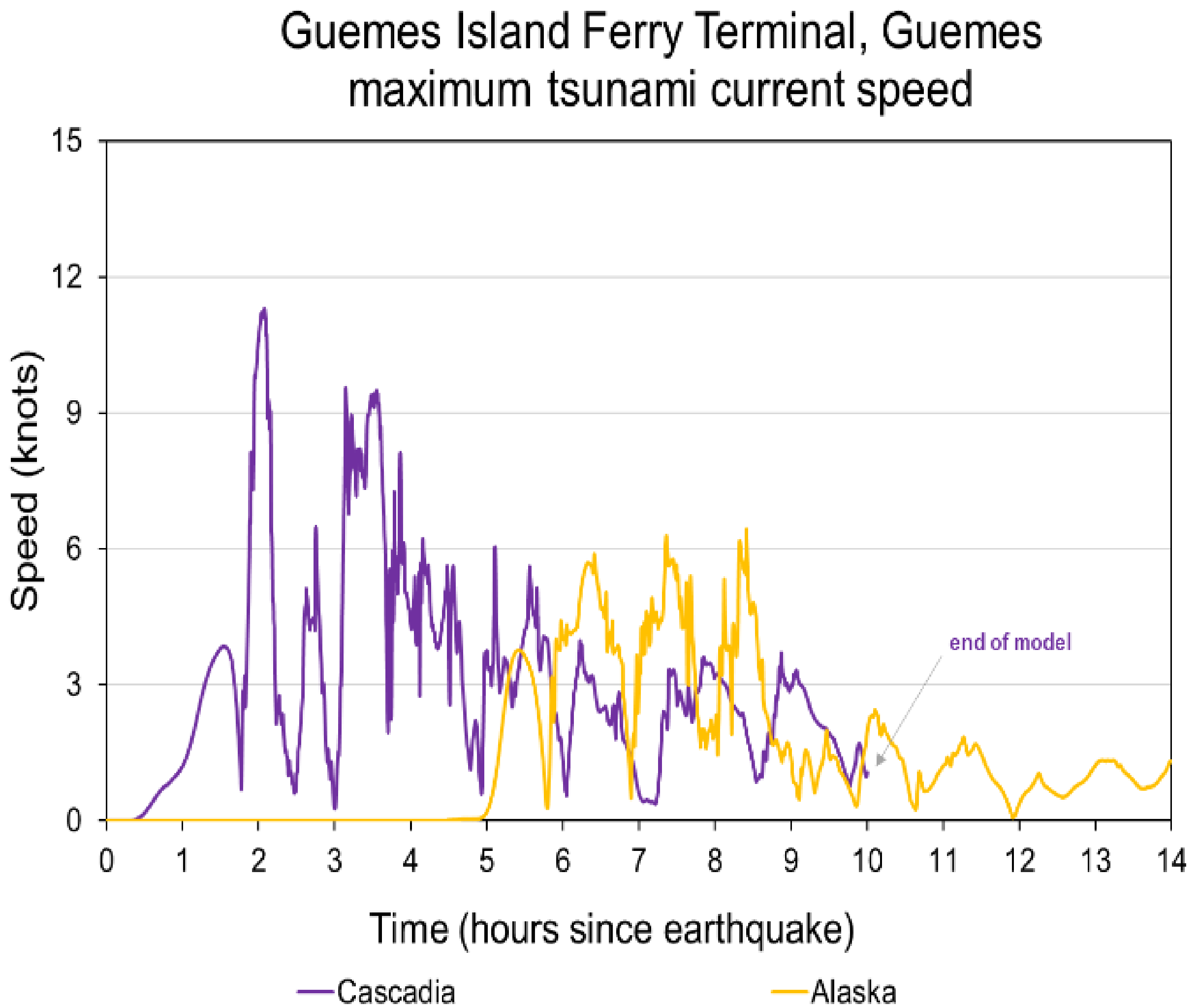

Figure 27: Modeled tsunami current speed over time at the Guemes Island Ferry Terminal synthetic tide gauge on the Guemes Island side. Location: Latitude 48.5277852, Longitude -122.6247258. Purple and yellow lines represent simulations from the Cascadia and Alaska-Aleutian subduction zone earthquake scenarios, respectively. Reported speeds are maximum values generated from either the mean high water or mean low water simulations.

Guemes Island Ferry Terminal, ferry route center: Current speeds

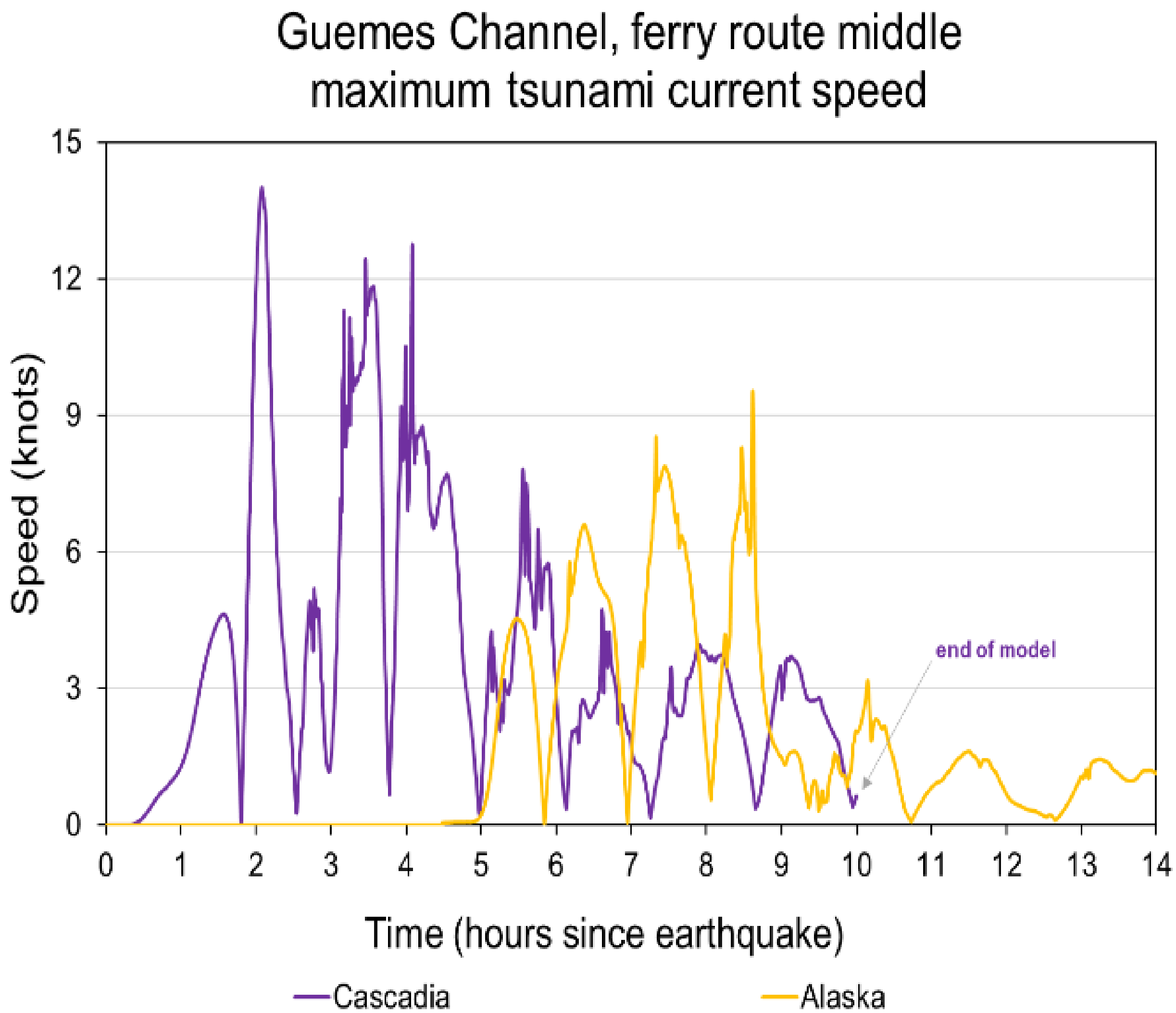

Figure 28: Modeled tsunami current speed over time at the middle of the Guemes Channel ferry route synthetic tide gauge. Location: Latitude 48.5240652, Longitude -122.6239371. Purple and yellow lines represent simulations from the Cascadia and Alaska-Aleutian subduction zone earthquake scenarios, respectively. Reported speeds are maximum values generated from either the mean high water or mean low water simulations.

Port of Anacortes, offshore Pier 1: Current speeds

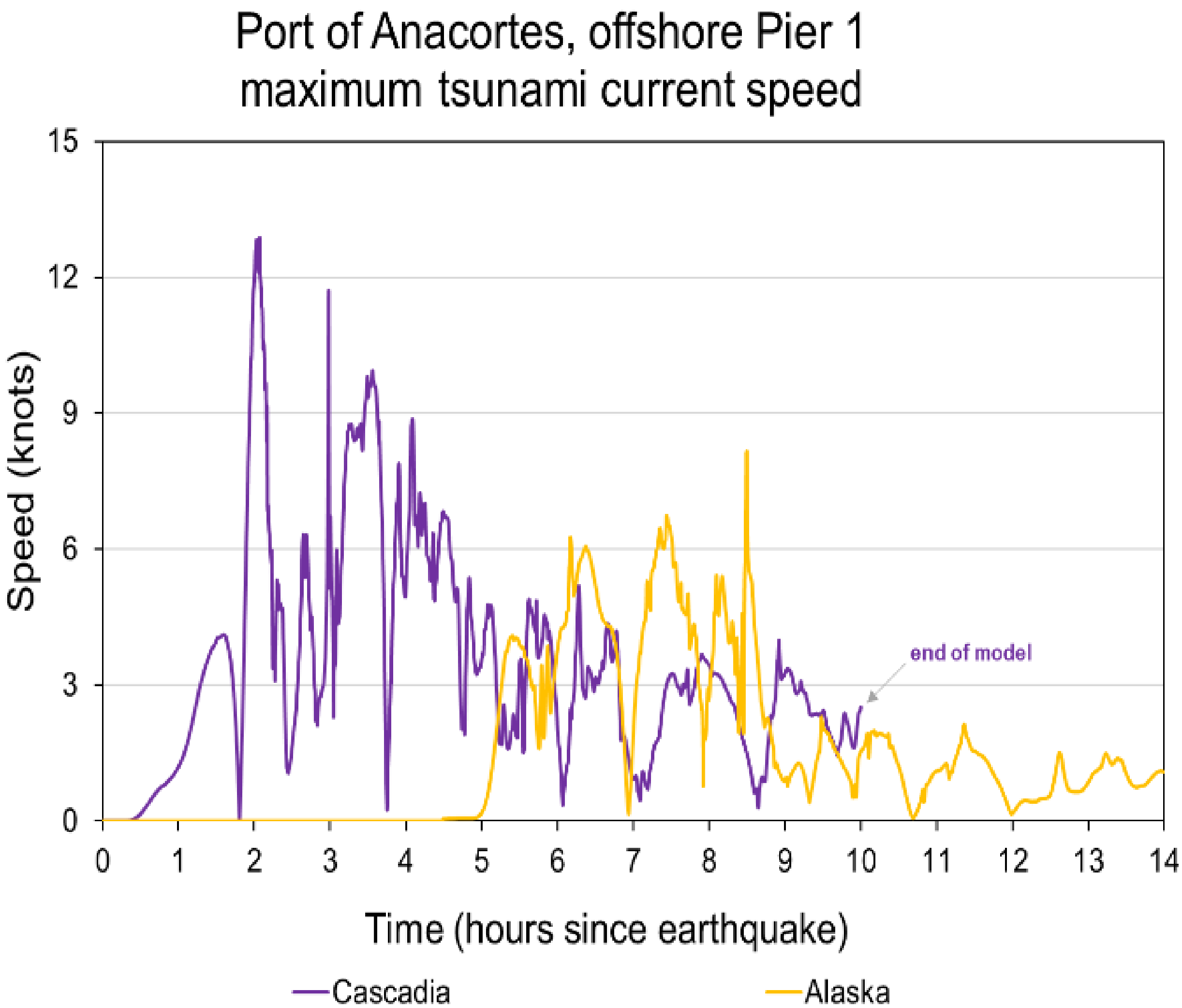

Figure 29: Modeled tsunami current speed over time at the offshore Pier 1 synthetic tide gauge. Location: Latitude 48.52310181, Longitude -122.6121826. Purple and yellow lines represent simulations from the Cascadia and Alaska-Aleutian subduction zone earthquake scenarios, respectively. Reported speeds are maximum values generated from either the mean high water or mean low water simulations.

Cap Sante Marina entrance: Current speeds

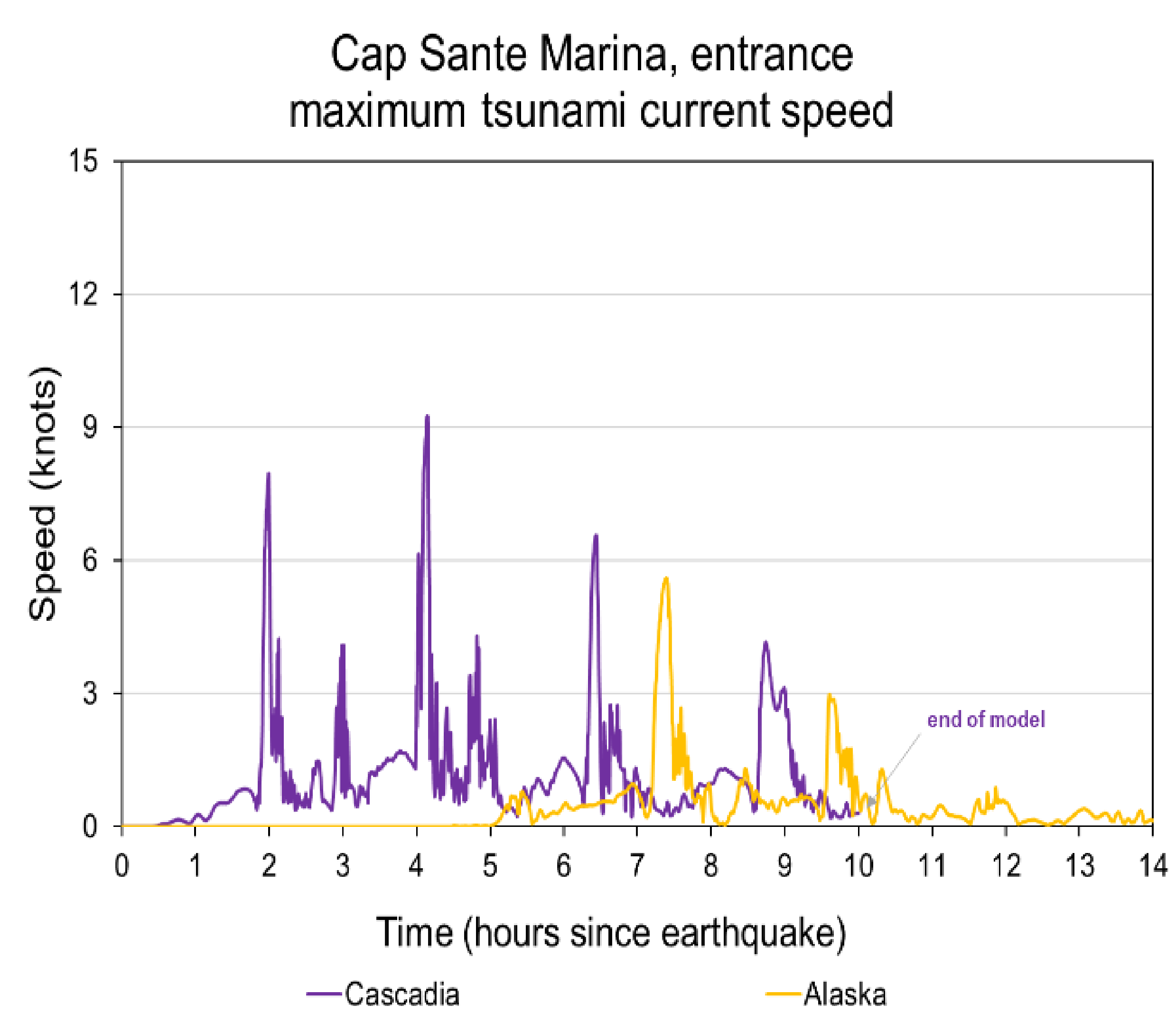

Figure 30: Modeled tsunami current speed over time at the entrance to Cap Sante Marina synthetic tide gauge. Location: Latitude 48.5113996, Longitude -122.6055116. Purple and yellow lines represent simulations from the Cascadia and Alaska-Aleutian subduction zone earthquake scenarios, respectively. Reported speeds are maximum values generated from either the mean high water or mean low water simulations.

Tsunami Minimum Water Depth Results

This section shows the minimum water depths possible within Guemes Channel from each tsunami scenario if the tsunami arrived at mean low water (providing the most conservative results). The following figures (Figures 32-37) represent the depths of water in three-foot intervals up to 21+ feet and can assist with estimating vessel grounding potential in different locations. Grounding will be dependent on both the available water depth and the overall drought of a given vessel. The amount of water drawdown caused by the tsunami can also be inferred when comparing the modeled minimum water depths to normal. Synthetically placed tide gauges included in the next section, *Timing of Tsunami*, also help visualize what possible drawdown may look like during the tsunami as offshore wave amplitudes fluctuate over time. Much like the first rising wave (crest) does not always equal the highest wave amplitude, the first falling wave (trough) does not always equate to the most water drawn out during a tsunami event.

In both earthquake scenarios, significant water drawdown takes place throughout the tsunami simulation, potentially exposing much of the seafloor. Areas susceptible to the largest drawdowns of water include the majority of Fidalgo Bay, Cap Sante Marina, offshore March Point, and the waterfronts along the Guemes Channel. Refer to figure 31 which records the approximate distance from shore at key locations that each tsunami scenario draws out water to less than three feet (lightest blue color in each figure).

Location	Approximate distance from shore with less than 3 feet water depth (feet)	
	CSZ scenario	*AASZ scenario*
Anacortes Ferry Terminal	180	100
Lovric's Marina	460	350
Guemes Island Ferry Terminal (Fidalgo)	220	130
Guemes Island Ferry Terminal (Guemes)	150	120
Port of Anacortes, Pier 1	80	60
March Point	2080	1970

Figure 31: approximate distance from shore at key locations that each tsunami scenario draws out water to less than three feet.

Overview: Cascadia Subduction Zone scenario

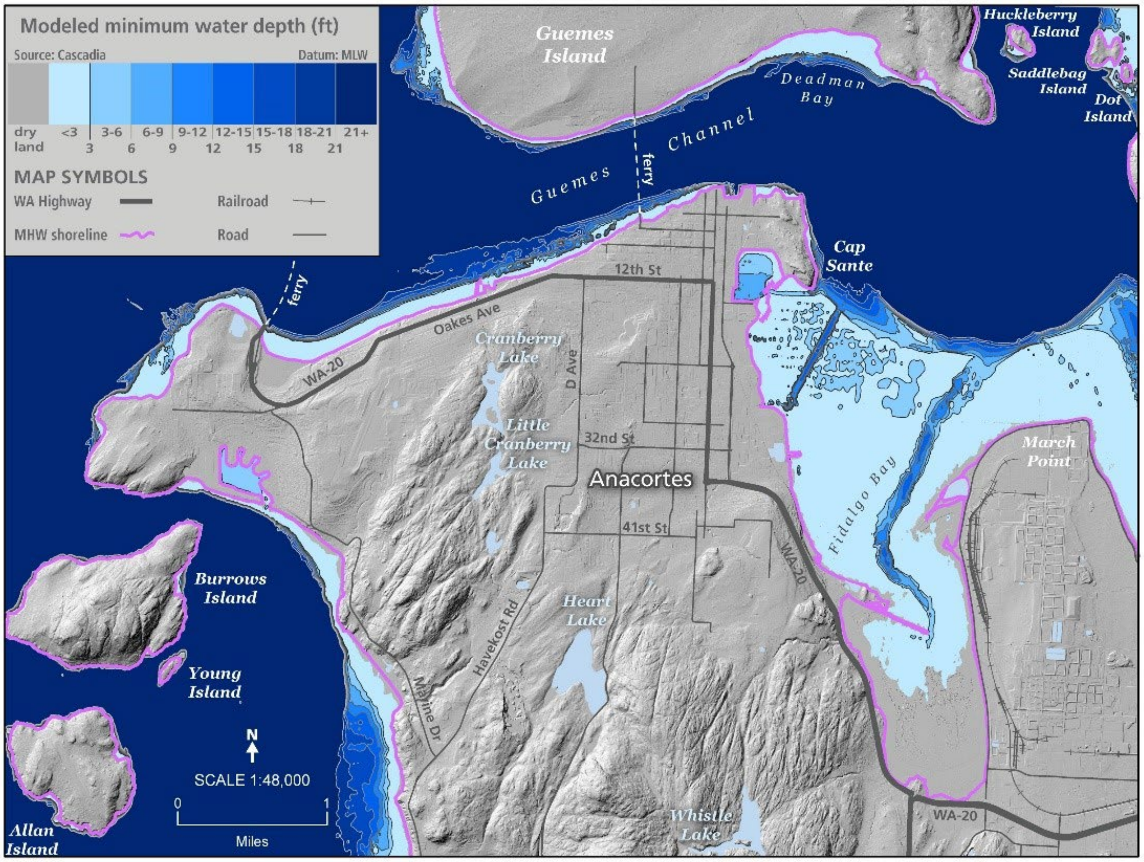

Figure 32: Overview of modeled minimum water depths from the Cascadia subduction zone earthquake scenario. Tidal datum: mean low water. Model resolution: 1/3rd arc-second (10 m).

Overview: Alaska-Aleutian Subduction Zone scenario

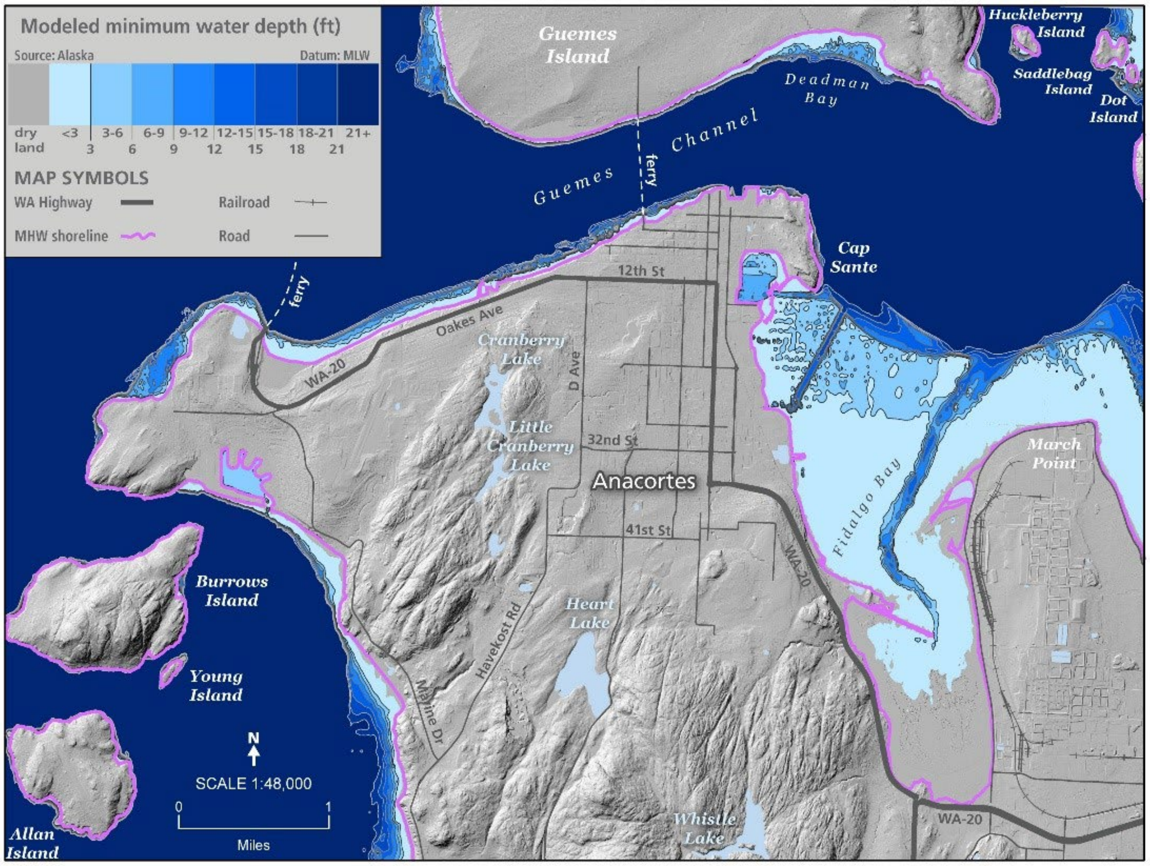

Figure 33: Overview of modeled minimum water depths from the Alaska-Aleutian subduction zone earthquake scenario. Tidal datum: mean low water. Model resolution: 1/3rd arc-second (10 m).

Cap Sante Marina: Cascadia Subduction Zone scenario

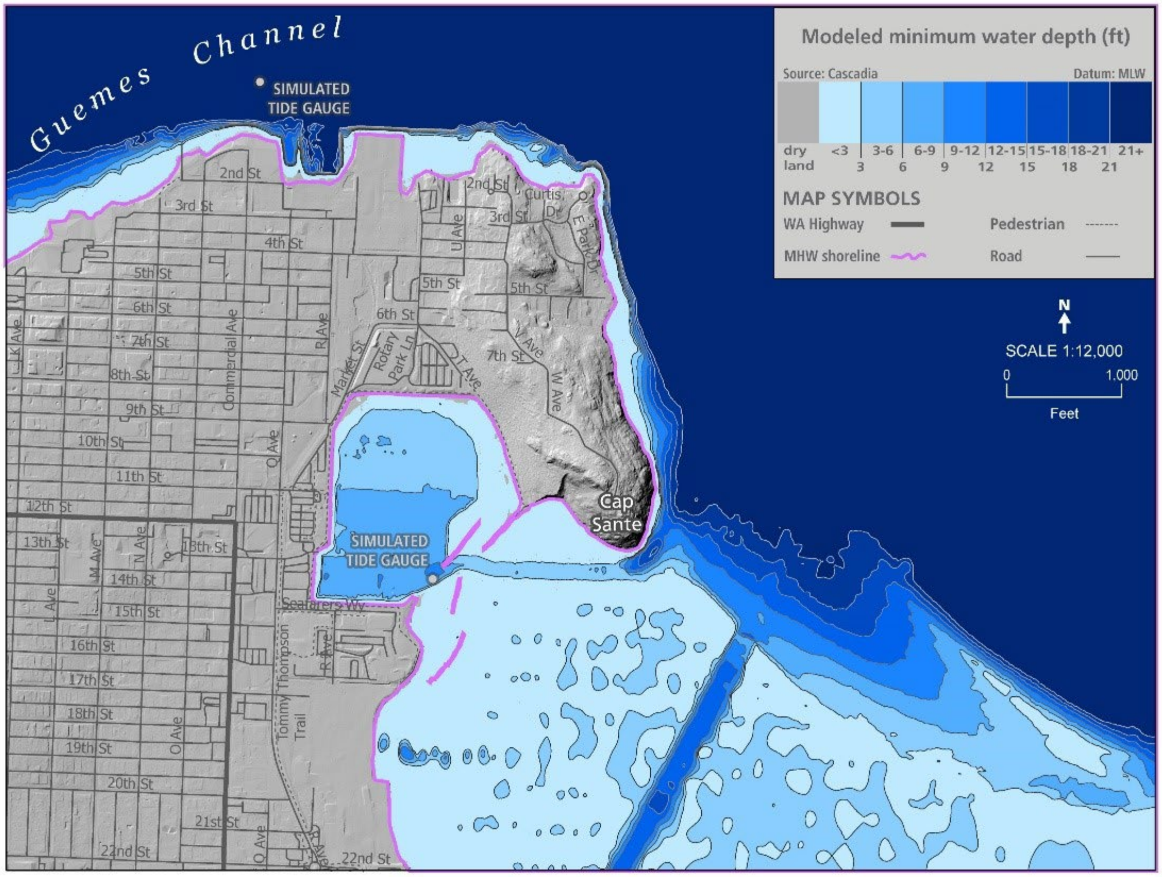

Figure 34: Modeled minimum water depths at Cap Sante Marina from the Cascadia subduction zone earthquake scenario. Tidal datum: mean low water. Model resolution: 1/9th arc-second (3 m).

Cap Sante Marina: Alaska-Aleutian Subduction Zone scenario

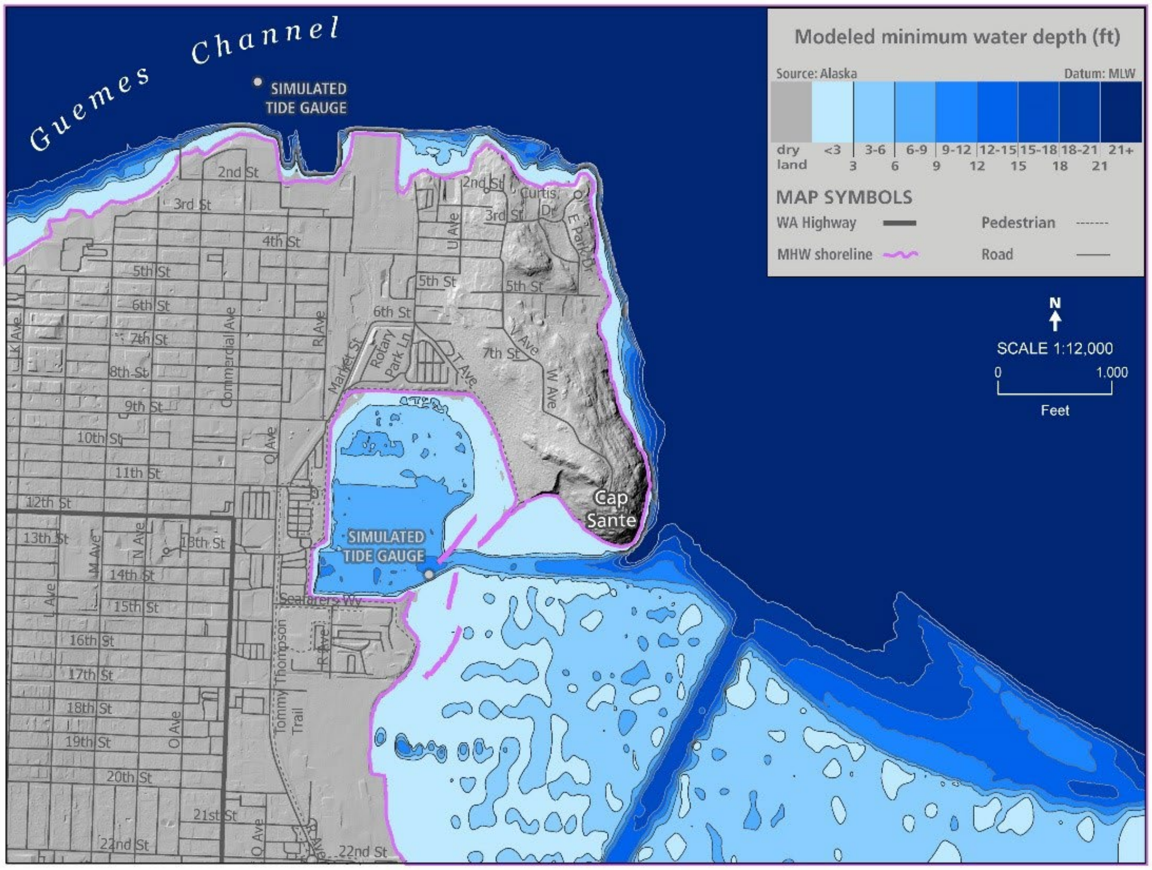

Figure 35: Modeled minimum water depths at Cap Sante Marina from the Alaska-Aleutian subduction zone earthquake scenario. Tidal datum: mean low water. Model resolution: 1/9th arc-second (3 m).

Guemes Island Ferry Terminal: Cascadia Subduction Zone scenario

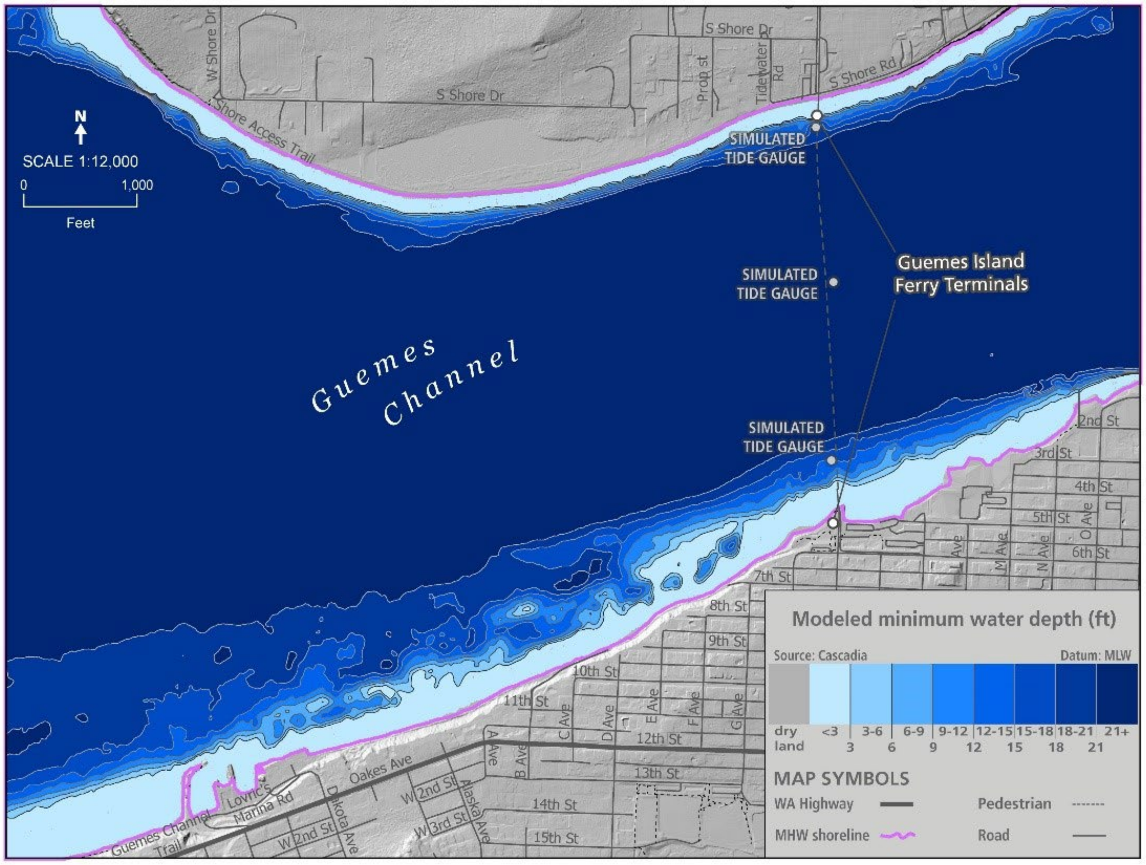

Figure 36: Modeled minimum water depths at the Guemes Island Ferry Terminal from the Cascadia subduction zone earthquake scenario. Tidal datum: mean low water. Model resolution: 1/9th arc-second (3 m).

Guemes Island Ferry Terminal: Alaska-Aleutian Subduction Zone scenario

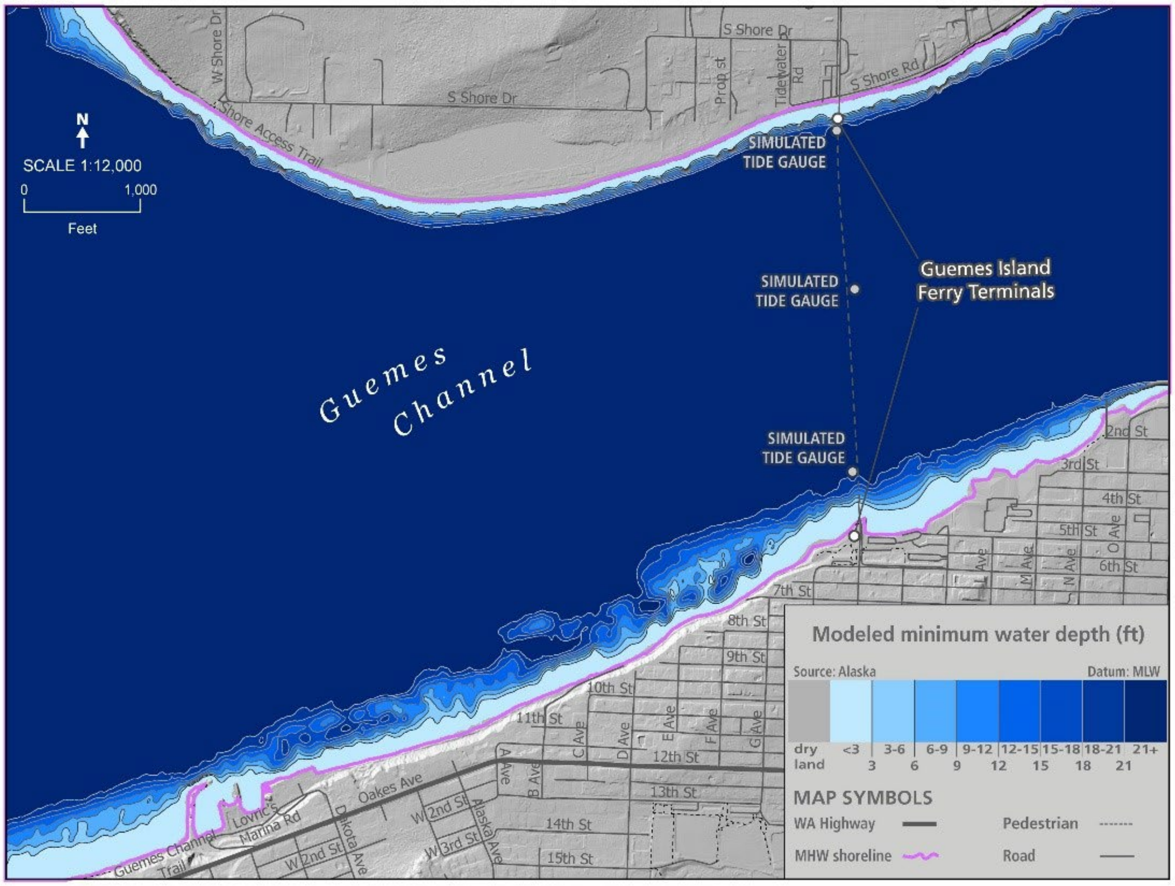

Figure 37: Modeled minimum water depths at the Guemes Island Ferry Terminal from the Alaska-Aleutian subduction zone earthquake scenario. Tidal datum: mean low water. Model resolution: 1/9th arc-second (3 m).

Timing of Tsunami Results

Effective tsunami preparedness and response planning first requires an understanding of the timing for when tsunami impacts begin. This section includes graphical data of the tsunami scenarios over simulated time recorded at six synthetic tide gauge locations to better envision when the tsunami waves arrive and how long impacts persist. Each synthetic tide gauge recorded both wave amplitudes and current speeds over the course of 10 simulated hours for the CSZ tsunami scenario and 14 simulated hours for the AASZ tsunami scenario.

Based on the tide gauge location at the Anacortes Ferry Terminal (the westernmost gauge location closest to the tsunami sources), the initial signs of the tsunami within Guemes Channel becomes apparent just after 20 minutes for the CSZ scenario (Figure 38) and after 4 hours and 50 minutes for the AASZ scenario (Figure 39). This is the first time when water surface heights begin to fluctuate from normal in each event (1-inch change).

One major difference between the two earthquake scenarios is that the CSZ tsunami first arrives with water levels dropping (a trough), while the AASZ tsunami arrives with water levels rising (a crest). Notably, the initial trough of the CSZ tsunami is long-lasting. After the modeled tsunami first arrives the water level within the Guemes Channel continues to drop for another ~30 minutes before the total amount of drawdown is greater than 1 foot. This first modeled trough of the CSZ tsunami scenario persists longer and does not transition to a rising wave greater than 1 foot for approximately 1 hour and 25 minutes after the initial tsunami signal. This totals an elapsed time of ~1 hour and 45 minutes from the start of the earthquake to when the first inundating waves arise. At the Anacortes Ferry Terminal tide gauge, the first rising wave from the CSZ scenario reaches a maximum wave amplitude of 13 feet approximately 10 minutes later, 1 hour and 55 minutes after the start of the earthquake (Figure 38).

Modeled wave heights from the AASZ scenario are lower than the CSZ scenario and arrive much later in comparison. For instance, the modeled maximum offshore wave height at the Anacortes Ferry Terminal tide gauge from the AASZ tsunami scenario equates to just over 4 feet and arrives approximately 5 hours and 15 minutes from the start of the earthquake (25 minutes after the initial tsunami arrival). For this scenario, the first wave does not transition to a significant drawdown of water (greater than 1-foot) until 5 hours and 45 minutes from the start of the earthquake (Figure 39).

At the Anacortes Ferry Terminal simulated tide gauge, the first wave crest is the highest in both the CSZ and AASZ scenarios, though the first wave troughs do not reflect the largest drawdowns. The following tables provide a summary of the timing since the start of the earthquake for 1) the initial tsunami arrival (±1 inch from normal), 2) the first 1-foot drawdown, 3) the first 1-foot rising wave, 4) the largest wave crest, and 5) the largest trough for both earthquake scenarios at key locations.

Cascadia scenario, timing since start of earthquake					
Location	**Initial Arrival (falling wave)**	**First 1-ft drawdown**	**First 1-ft rise**	**Maximum trough**	**Maximum crest**
Anacortes Ferry Terminal	20 min	50 min	1 hr and 45 min	3 hr and 30 min	1 hr and 55 min
Guemes Island Ferry Terminal, Fidalgo	25 min	55 min	1 hr and 50 min	3 hr and 35 min	2 hr and 55 min
Guemes Island Ferry Terminal, Guemes	25 min	55 min	1 hr and 50 min	3 hr and 35 min	2 hr and 55 min
Guemes Island Ferry Terminal, ferry route center	25 min	55 min	1 hr and 50 min	3 hr and 35 min	2 hr and 55 min
Port of Anacortes, offshore Pier 1	25 min	60 min	1 hr and 50 min	3 hr and 50 min	2 hr and 55 min
Cap Sante Marina, entrance	35 min	65 min	2 hr	4 hr	3 hr

Figure 38: Estimated wave arrivals following the start of a Cascadia scenario earthquake.

Alaska scenario, timing since start of earthquake						
Location	Initial arrival (rising wave)	First 1-ft drawdown	First 1-ft rise	Maximum trough	Maximum crest
Anacortes Ferry Terminal	4 hr and 50 min	5 hr and 45 min	5 hr	6 hr and 40 min	5 hr and 15 min
Guemes Island Ferry Terminal, Fidalgo	4 hr and 55 min	6 hr and 10 min	5 hr and 5 min	7 hr and 5 min	8 hr and 30 min
Guemes Island Ferry Terminal, Guemes	4 hr and 55 min	6 hr and 10 min	5 hr and 5 min	7 hr and 5 min	8 hr and 35 min
Guemes Island Ferry Terminal, ferry route center	4 hr and 55 min	6 hr and 10 min	5 hr and 5 min	7 hr and 5 min	8 hr and 30 min
Port of Anacortes, offshore Pier 1	4 hr and 55 min	6 hr and 10 min	5 hr and 5 min	7 hr and 5 min	8 hr and 10 min
Cap Sante Marina, entrance	5 hr	6 hr and 25 min	5 hr and 15 min	7 hr	8 hr and 15 min

Figure 39: Estimated wave arrivals following the start of an Alaska scenario earthquake.

Note that the fastest speeds can occur during both wave troughs and wave crests. Overall wave activity may continue longer than the 10 and 14 hours modeled in this strategy and even minor inundation and increased current speeds could pose delays to initial rescue and recovery operations. For example, the 1964 Mw 9.2 Great Alaskan Earthquake affected local wave currents offshore of Alaska for more than 24 hours after the earthquake, and the January 26, 1700 CSZ earthquake produced a tsunami that may have lasted as many as 20 hours in Japan (Satake and others, 2003; Atwater and others, 2005).

Limitations and Uncertainty of the Model

Earthquake rupture patterns often vary significantly from one earthquake sequence to the next. Additionally, the two earthquake fault models used to generate the simulated tsunami have simplified regional slip distributions that only generate vertical displacement within their fault geometries, rupture instantaneously, and do not include more complex components that could alter tsunamigenesis (such as material heterogeneity in the subduction zone, inelastic behavior, horizontal slip components, extensional faulting within the subduction zone, or dynamic coseismic deformation). Due to these simplifications, the largest source of uncertainty in this modeling relates to the selected earthquake scenarios and their respective deformation process. The modeled CSZ and AASZ earthquake scenarios are considered deterministic by nature and will not provide an exact representation of a tsunami generated by the next earthquake within these subduction zones.

Furthermore, the tsunami model software package, GeoClaw, used to generate the results presented in this strategy does not include physical processes such as localized topographic changes to the DEMs (digital elevation models) caused by sediment deposition/erosion and liquefaction, or a dynamic tide stage in the model setup. A tsunami arriving on a rising versus falling tide may amplify or reduce the impact of the tsunami, respectively. Due to the uncertainty of the tide stage in the next tsunami, this strategy provides tsunami impacts on either a static mean high tide (maximum inundation) or mean low tide (minimum water depths) for conservatism. However, the next tsunami may arrive anywhere in between these tide stages and the diurnal range (the difference in height between high tide and low tide) at Anacortes is ~5 feet. Additionally, the tsunami model does not include interactions between an ebbing wave, a subsequent flooding wave, or interactions with normal tidal currents. These interactions can be additive to the tsunami wave if in the same direction or steepen the tsunami wave front and cause a breaking wave if in an opposing direction (Zhang and others, 2011).

All tsunami simulations ran on bare-Earth DEMs, meaning they did not include the onshore built environment or vegetation. Not including these features generally produces greater inundation and a more conservative model result compared to if they were included. However, simulating a model that assumes bare-earth topography may neglect possible localized effects that vegetation and structures can have on the path and flow of the tsunami. For example, higher fluid velocities and greater turbulence, along with different trajectories may exist than what is included in this strategy for areas where a neighboring building or vegetation could channelize flow leading to locally faster current speeds. A more realistic assessment of tsunami impacts would require additional site-specific modeling using an all-returns topographic model (incorporating buildings, vegetation, and infrastructure).

The CSZ tsunami results do not account for any possibility of seismically induced landslides from the regional earthquake shaking. Coseismic landslides sliding into the Salish Sea have the potential to generate various tsunami waves that could arrive much earlier than the timings presented. This modeling does not include any foreshocks or aftershocks either, which may also cause tsunamigenic slope failures within or near the Guemes Channel.

Lastly, it should be noted that the results from the AASZ tsunami scenario may be overestimated by ~10-15%. This is due to the realization of missing source terms in the mass equation built into the GeoClaw code that was discovered after the completion of the modeling. Without these source terms, the modeled tsunami would decay less than it should when propagating south over a long distance from higher to lower latitudes, such as from the AASZ to Washington. This result was confirmed in a rerun of the AASZ tsunami scenario for the Guemes Channel simulated at mean high water when compared to the original results; offshore tsunami wave heights and current speeds were slightly less in the rerun with the source terms included than without. However, the slight decrease in overall wave heights and current speeds were not great enough to alter the proposed mitigation measures included in this strategy from the modeling that omitted these terms. Thus, this strategy has opted to report the results of the AASZ tsunami simulations that omitted these source terms for overall conservatism, especially when considering the large amount of uncertainty associated with the AASZ fault model, among the other limitations described in this section. In this strategy, the absence of these terms in the GeoClaw mass equation is only admissible to the modeled AASZ-generated tsunami and is not significant to results of the CSZ tsunami simulations. This is largely because the modeled CSZ-generated tsunami propagates east-west to Washington at similar mid-latitudes and not from one latitude to a very different latitude.

Section 4: Tsunami Response Guidance

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

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

Tsunami Response Actions

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

Shut Down Port Infrastructure Before Tsunami Arrives

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

Evacuate Public/Vehicles from Waterfront Areas

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

Personal Floatation Devices/Vests for Port Staff

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

Informing and Coordinating with Key First Responders During a Tsunami

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

Remove or Secure Hazardous Materials Used or Owned by Port

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

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

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

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

Activate Incident Command at Evacuation Sites

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

Move Vessels Out of the Port

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

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

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

Activate Mutual Aid System as Necessary

Activation of a Mutual Aid System can help locations experiencing an emergency receive additional assistance from nearby jurisdictions that are not part of the emergency or are less impacted by it. Activating this type of system allows authorities in an area struck by a disaster access to additional resources that may be scarce during the initial response or may be needed in numbers that exceed the amount available in the disaster area.

Reposition Ships Within the Port

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

Stage Emergency Equipment Outside Affected Area

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

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

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

Secure Moorings of Port Owned Vessels

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

Remove Small Vessels from the Water

Tsunamis can generate an extensive amount of debris which can damage vessels and other marine assets due to fluctuating current speeds, inundation, and drawdown. Prior to tsunami wave arrival, ports and marinas may be able to remove their assets and smaller vessels from the water and encourage their users to do the same. This could reduce the potential for these vessels and assets to be damaged by debris or become drifting debris themselves. However, the ability to remove vessels and assets from the water is dependent on the tsunami's estimated wave arrival time. While there may be enough time to execute this process for distant source tsunamis, there may not be enough time to do so during most local source tsunamis. Removal would also be a time-consuming and labor-intensive process which would require adequately trained personnel and may require specialized equipment such as shoreside boat lifts and trailered vehicles to remove vessels from the water. To effectively coordinate this process, proper training and exercise would need to be provided for port staff and its users would need to be informed of those processes and recommendations. If a port or marina owns vessels essential to life safety, such as equipment used for search and rescue operations, fire and spill response, and law enforcement activities, they should be prioritized for removal from the water.

Remove Buoyant Assets Out of and Away from the Water

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

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

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

Feasibility of Tsunami Response Guidance for the Port of Anacortes

In the comprehensive evaluation of tsunami response actions for the Port of Anacortes and the Guemes Channel area, each potential action was evaluated based on its feasibility, classifying them as either 'Feasible,' 'Needs Review,' or 'Not Feasible.' This critical analysis takes into account the unique characteristics and vulnerabilities of the Port of Anacortes and the Guemes Channel area. The applicability of these response actions extends to scenarios involving both a Cascadia Subduction Zone (CSZ) and an Alaskan-Aleutian Subduction Zone (AASZ) earthquake-generated tsunami.

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

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

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

Pre-Identify Personnel to Assist in Rescue, Survey and Salvage Efforts	**Needs Review**
Secure Moorings of Port Owned Vessels	**Not Feasible**
Remove Small Vessels from the Water	**Not Feasible**
Remove Buoyant Assets Out of and Away from the Water	**Not Feasible**
Restrict Boats from Moving and Prevent Ships from Entering the Port During a Tsunami	**Not Feasible**

Shut Down Port Infrastructure Before Tsunami Arrives

Feasibility for The Port of Anacortes: Feasible

Although there are no currently outlined standard operating procedures (SOPs) to shut down Port infrastructure, it's feasible for the Port to turn power, water, and fuel lines off once a tsunami alert has been received. During a tsunami, the Port can accomplish this response action; it takes about 1 minute to shut off fuel lines but a substantially longer time to shut off water and power lines. One of the marine terminals has a more complex power system containing multiple power generators that could take more time to shut down completely. To implement this response action, the Port would need to develop an SOP that outlines communication and coordination procedures for staff to initiate shut off protocols, including decision trees that outline the circumstances to shut off power, water, and/or fuel during tsunamis. Additionally, to shorten the amount of time needed to shut off these systems, it's recommended to do a study investigating opportunities for improved efficiencies.

A few challenges to implementing this response action identified by Port personnel include decision points around when to shut off the power, as this could potentially cut off both internal and external critical communications lines. Another major concern is that in a large tsunami incident, the main power farm is within the inundation zone and could sustain heavy damages that impact power needs in response and recovery efforts for the city. It is recommended that the Port of Anacortes therefore work with the City of Anacortes and Puget Sound Energy to create clearly outlined procedures for shutting down critical infrastructure. Working with external and internal stakeholders can allow the Port to effectively plan for communications needs when a tsunami alert is received and build redundancy to ensure that relevant stakeholders maintain situational awareness as the first wave approaches.

Evacuate Public/Vehicles from Waterfront Areas

Feasibility for the Port of Anacortes: Feasible

Once the City of Anacortes has been alerted to a tsunami, the Anacortes Police Department and other first responders will take efforts to close off access to the expected inundation zone. The City has already identified several designated evacuation areas at several schools and large Port-owned parking lots further inland for both pedestrian and vehicular traffic. The Port of Anacortes will send out an alert via AlertSense with recommended actions in addition to automated WEA messaging sent out from Skagit County for all areas within 2 miles of the shoreline. Evacuation will be supported by the Anacortes Fire and Police Departments and Skagit County Department of Emergency Management.

Many factors complicate evacuation planning for the City of Anacortes. If the Guemes Island Ferry is on the water and not docked during the time of earthquake shaking and/or receipt of a tsunami alert, people on board will need to evacuate off the vessel. If the ferry is docked in the Port of Anacortes, Anacortes Police will shuttle people directly to the airport. If a large earthquake precedes a tsunami alert, transportation may be cut off to I-5 if the Highway 20 bridge southeast of Anacortes fails. It is recommended that the City work with first responders and emergency management personnel to create a traffic management plan should either of the above scenarios come into play, including close collaboration with the Guemes Island Ferry captain, and develop procedures dependent on the location of the ferry at the time of the incident/alert. The City will also be responsible for making the decision to allow members of the public to return to impacted areas post-tsunami and should outline these procedures and decision points. Once these have been identified and outlined in the associated agencies' response plans, this provides an excellent opportunity for the City, local agencies, and the Port to conduct an exercise on tsunami evacuation.

Personal Floatation Devices/Vests for Port Staff

Feasibility for the Port of Anacortes: Feasible

All Port of Anacortes staff and crew are issued personal floatation jackets, which they are required to wear when on or near the water, and the Port has sufficient additional jackets for all office staff. It is recommended the Port impress upon all staff the importance of wearing these devices if responding during a tsunami.

Informing and Coordinating with Key First Responders During a Tsunami

Feasibility for the Port of Anacortes: Feasible

Regardless of whether a tsunami impacting Anacortes is local or distant, many local agencies will be involved from the beginning in protective actions, response, and recovery. The Port itself has very limited decision-making authority when it comes to emergencies and disasters as local emergency management takes the lead. With this said, the Port and its staff can be an asset to other jurisdictions during response. Each of the agencies are responsible for different geographic locations, decision-making, and/or response actions and it is therefore vital that all are communicating frequently to avoid confusion and duplication of effort.

The Port does not currently have any outlined plans to communicate its status or needs to the Skagit County Department of Emergency Management. While the Skagit County Department of Emergency Management does participate in the state/local conference calls coordinated by the WA Emergency Management Division during tsunami response, there is recognition from relevant stakeholders that more can be done to ensure two-way communication is happening throughout a tsunami incident. Currently, the Port has a VHF radio at Cap Sante Marina. It's possible that the Port could procure more mobile VHF radios to communicate with County EOC for resources and add Skagit County Department of Emergency Management VHF channel to their radios. It is also recommended that the Skagit County Department of Emergency Management work with the City and other agencies overseeing critical infrastructure in the area to establish and maintain emergency communications lines to ensure that accurate damage assessments and response/recovery needs are being communicated up to the state level and state-level communications are being funneled down to relevant personnel at the local level. This system should be expanded County-wide across other hazards as well.

To consolidate tsunami response communication efforts, the Skagit County Department of Emergency Management should consider initiating their own hourly local conference calls (following WA EMD's state/local conference call) like Grays Harbor County Department of Emergency Management's conference calls. Representatives of the Grays Harbor County's emergency and law enforcement committees also participate in the Port of Grays Harbor's conference calls. If the Skagit County Department of Emergency Management considers organizing a similar conference call during tsunamis, they will need to ensure the proper stakeholders responsible for initiating response actions during tsunamis are on the call.

Remove or Secure Hazardous Materials Used or Owned by Port

Feasibility for the Port of Anacortes: Needs Review

It is recommended the Port of Anacortes update emergency response plans to include procedures for securing Port-controlled chemical and waste storage. This would involve a review of Port-owned and used chemical storage. In addition, there is an extensive runoff drainage system leading to a collection pool on Port property used to better control runoff pollutants into the Guemes Channel. The Port should review potential response capabilities that could prevent the contents of this pool from spilling into the Channel during tsunamis. SOPs would need to be developed that outline roles and responsibilities to prevent spillage if there is enough time to do so prior to tsunami wave arrival. These SOPs would need to be reviewed and tested regularly, and updated if the Port acquires additional chemical storage, to ensure effective response during a tsunami. Privately owned vessels, assets, and other facilities in the Port may also contain similar hazardous materials. During ongoing outreach with users, boaters, and tenants, the Port can better inform them of personal response actions they can take to secure these materials.

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

Feasibility for the Port of Anacortes: Needs Review

The Port of Anacortes has already established redundant communications to notify boat owners of an emergency by partnering with the Skagit County Department of Emergency Management. The Skagit County Department of Emergency Management will send out a Reverse 911 alert message. Additionally, the public receives alerts disseminated by NOAA Weather Forecast Offices through NOAA weather radios and the Emergency Alert System (EAS). Members of the Port are required to sign up for an AlertSense list that the Port manages when they dock their boats to ensure that all boat owners receive a notification in the event of an emergency. It is recommended that the Port and City ensure that all relevant parties are receiving alerts and update the lists on a regular basis.

Cap Sante Marina offers liveaboard moorage for boats that are larger than 32’ and limits the number of liveaboards to 100 vessels. There are specific requirements for liveaboards when they register, including for boats to be seaworthy and to be immediately ready for cruising in local waters. As part of the registration process, each person is also automatically signed up for AlertSense. During this registration process, it’s also possible to have them to sign up for Reverse 911 and other alerts to get the most up to date and local information they may need during emergency response. This may be a good opportunity to share tsunami educational materials as well, including the WA EMD Tsunami Boater’s guide.

Activate Incident Command at Evacuation Sites

Feasibility for the Port of Anacortes: Needs Review

Command and Control for the Port of Anacortes currently will be managed from their corporate offices in conjunction with local responders rather than at evacuation sites. The Port should explore other options for activating incident command during tsunamis in a location outside of the modeled inundation zone. It is also recommended Port staff be trained in ICS so they can better understand its use during tsunamis and provide more knowledgeable, experienced assistance to responding agencies. ICS training is not currently required for Port of Anacortes staff but should be considered for at least those personnel with decision-making authority and other key responsibilities, so they are better able to coordinate with and support responders. Many ICS classes are free, can be completed online at your own pace, and do not require a huge time commitment. Even a basic understanding of ICS will improve Port staff’s effectiveness during a tsunami.

During a tsunami, Skagit County Department of Emergency Management (DEM) would open their Emergency Operations Center (EOC) at their building in Mount Vernon. Skagit County DEM would send liaisons, as needed and requested, to local EOCs. Incident Command would be run by the Anacortes Fire Department and Police Department, but procedures for initiating this would need to be reviewed. Evacuations sites would be operated by the American Red Cross or by Skagit County DEM’s Emergency Volunteer Groups and they would have communications with them to coordinate operations and supplies; however, there is no official Skagit County DEM Incident Command Post at these sites.

Move Vessels Out of the Port

Feasibility for the Port of Anacortes: Needs Review

There are several areas of concern when it comes to this recommendation. First, based on the geographic layout of the San Juan Islands, deep water may be difficult to find, especially if numerous larger vessels such as ferries are looking to ride out the waves because they do not have time to dock and evacuate their crews and passengers. Additionally, modeled maximum current speeds may exceed >9 knots above normal in some parts of the Guemes Channel during both CSZ and Alaska tsunami scenarios, creating dangerous conditions for vessels to navigate. These concerns are heightened for a CSZ tsunami since the first 1-foot drawdown arrives at 50 minutes after the earthquake and the first rising wave arrives at about 1 hour and 45 minutes after the earthquake.

Second, the Port does not have any authority to instruct boat owners to take any specific actions related to leaving their vessels docked or taking them out on the water during a tsunami. While first responders may be evacuating coastal areas, many boat owners may try to reach their vessels to take them out to the Channel instead of leaving them docked. In addition, the Port and other surrounding private companies may at the same time be attempting to take their very large vessels (100+ feet in length) out to the open Channel, especially in the distant AK M9.2 scenario in which there may be several hours to react prior to wave arrival.

Third, many larger vessels require assistance navigating the Channel waters through specially trained personnel known as pilots, and only four such people are in the Anacortes area at any time. For the Port of Anacortes, the Puget Sound Pilots handle the movement of all ships and would make the decision whether to bring vessels into or out of the Port. This creates additional constraints that can affect decision making from the moment a tsunami alert is received, especially considering that most larger vessels take approximately an hour to prepare to launch. These pilots should be trained in what to do to protect vessels during a tsunami.

To determine if this process could safely take place, additional study and review is necessary. The Port of Anacortes would have to coordinate with other local, state, and federal agencies to determine feasibility of staging areas for both commercial and recreational vessels. WA EMD can facilitate conversations with the U.S. Coast Guard and Puget Sound Pilots to benefit not only the Port of Anacortes but other ports, harbors, and marinas in Washington as well. This coordination would be essential since the Port does not have the authority to handle vessels or require vessels to move during a tsunami. Early conversations have explored the possibility of moving ships north towards Bellingham Bay, although no decisions have been made and there is uncertainty as to whether ships would be moving south from the Bellingham area/Canada as well.

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

Feasibility for the Port of Anacortes: Needs Review

Evacuations from the Port inland to high ground should not be difficult to achieve given the 1 hour and 45-minute arrival time of the first waves in the event of the CSZ scenario. However, evacuations should not be delayed or postponed. The notice to evacuate should be given immediately after ground shaking or receipt of a tsunami alert to account for any hazards that resulted from the earthquake, account for infrastructure damage, traffic conditions, weather, or other unknown factors. Responsibility for evacuating people from the waterfront area of Anacortes falls under the City of Anacortes and their first responders, not the Port of Anacortes.

The Port will send out an AlertSense message directing people to evacuate from vessels and to high ground, at which point evacuees then fall under the direction of the City.

Currently, there is not a process in place for restricting traffic from entering the Port but there is a process to shuttle people off the Guemes Island Ferry during tsunamis. It is recommended that the City review and coordinate with other agencies to establish a plan that expands on aiding other evacuation traffic in shoreline areas, including pedestrians and vehicle traffic. Efforts to prohibit entry may be difficult due to limited staff and their availability during different times of day. When a plan is established, the Port should work with the City to identify any tasks which its staff can assist with in the Port areas during the evacuation process. The Port should educate personnel, tenants, and users about the ways in which they may receive communications from the Port and the Skagit County Department of Emergency Management during emergencies like tsunami evacuations. The Port should also train their staff on tsunami evacuation processes and test these processes by conducting regular drills.

Activate Mutual Aid System as Necessary

Feasibility for the Port of Anacortes: Needs Review

The Port of Anacortes is a public-private partnership with its own elected officials. While the Port has the authority to administer itself, it does rely upon the City of Anacortes for support and public safety resources. This means the Port does not have response authority or capability but is still responsible for managing the infrastructure of the Port of Anacortes. The Anacortes Police Department has law enforcement authority for the Port and the Anacortes Fire Department has emergency medical service authority for the Port. They are not considered mutual aid systems but responsible agencies and as such are able to request mutual aid on behalf of the Port. During any emergency incident the Port's primary role is to provide information to boaters and users, notify the proper authorities, and work with responders as needed.

It is recommended that a Skagit County Tsunami Action Plan be developed to highlight and determine what mutual aid systems are needed for tsunamis. The Port should then consider training their staff in how these systems work, what agreements are in place, and how mutual aid can be requested through the proper means to improve effectiveness during an actual tsunami.

Reposition Ships Within the Port

Feasibility for the Port of Anacortes: Needs Review

This process could potentially take place for the Port of Anacortes during tsunamis depending on a number of factors including, but not limited to timing of wave arrival/drawdown, current speed increase, size of vessels, and timing for movement of vessels. Up to 6 large vessels (65 to 650 feet in length) are in the Port of Anacortes at any time. These vessels are most likely to cause significant infrastructure damage due to their size, especially due to risk from high current velocities and thus could be repositioned within the Port to avoid such damage. These vessels are also most likely to have resident crew members on board, which increases the need to potentially reposition these ships as well as evacuate them prior to wave arrival for life safety.

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

On the east side of Cap Sante Marina, where a large amount of smaller commercial and recreational vessels are located, significant increases in current speeds is possible. In close collaboration with the Puget Sound Pilots and the U.S. Coast Guard, it’s possible to develop more robust guidance on how ships could be repositioned within the marina to best avoid areas of high currents during tsunamis.

Stage Emergency Equipment Outside Affected Area

Feasibility for the Port of Anacortes: Needs Review

The Anacortes Fire Department station is located close to the edge of the CSZ modeled inundation zone and is the main emergency response infrastructure at risk of being inundated from a Cascadia Subduction Zone tsunami. However, before removing any emergency equipment, the priority would be to evacuate all staff and personnel from the Anacortes Fire station. If the Skagit County DEM deems there to be enough time prior to wave arrival of a distant tsunami, emergency supplies and equipment may be able to be staged outside of the inundation zone. If this were the case, an area would need to be determined in collaboration with the City of Anacortes and incorporated as an official SOP for tsunami response.

Due to requirements of the U.S. Coast Guard, some of the private oil refineries have spill response materials and assets that are located close to the inundation zone to manage spill response on the water. This is in addition to a bus of emergency response equipment located along the eastern shore in Anacortes. It is possible that some of this oil spill response equipment on land could be moved outside of the modeled inundation zone, including using the local airport as an emergency equipment staging area. Pre-disaster contracts and/or memorandum of understandings should be established if any of these private refineries would like to assist in response.

Further discussions between the Port, City, and the Skagit County DEM (and possibly private industry stakeholders willing to assist in response) should work to identify and inventory relevant emergency equipment and identify the capacity to move equipment to safe areas outside the inundation zone.

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

Feasibility for the Port of Anacortes: Needs Review

Port staff do not have the knowledge or expertise to conduct extensive damage assessments post-tsunami nor are they able to provide guidance on reopening Port facilities. Following a tsunami, consultation from a maritime construction company or an engineering firm will be sought out to ensure that a complete assessment of Port facilities is performed. On-land assessments of facilities will also be required, especially for the nearby privately operated refineries. This is especially critical as the refineries maintain a significant role in the supply chain for fuel operations at local airports and other critical transportation that may be needed in emergency response, recovery, and containment of chemicals and fuel.

For a large local tsunami, there may be a limited number of people available to conduct these assessments due to high demand. Following a Cascadia Subduction Zone tsunami, it may take weeks for federal personnel to come evaluate facilities in the Guemes Channel, especially when competing with other impacted ports along the west coast. In response, local private companies such as US Ecology, Marine Spill Response Corporation (MSRC), Island Express, and San Juan Enterprise may play a significant role in assisting first responders in rescue, survey, and salvage efforts. This is especially important due to the limited capabilities of local first responders, as the Anacortes Fire Department expects only six or seven firefighters to be on duty at a time with access to only one watercraft. However, this is a time-consuming process as contracts need to be drawn up with private companies who provide resources in emergencies. The MSRC does run a “vessel of opportunity” program which allows owners to register their own boats to assist in response and recovery efforts. This would require some coordination with the refineries as requests to help with outside recovery efforts would have to be approved beforehand.

It is recommended the City and Port formalize pre-disaster relationships with private companies and members of the public to build rescue, survey, and salvage capabilities. This can be done through pre-disaster contracts or through the development of memoranda of understanding (MOAs). When possible, all relevant stakeholders in the Guemes Channel should be involved in the planning process to help establish roles and responsibilities, document capabilities, and create tasks to cover anticipated needs after a tsunami.

Additionally, the Port should clarify both internal roles and external agency coordination for survey and salvage efforts. Port staff will need to coordinate with and assist agencies that are involved in conducting survey safety assessments for their own facilities after a tsunami. The Port will need to ensure that proper training and exercising is provided to accomplish this.

Secure Moorings of Port Owned Vessels

Feasibility for the Port of Anacortes: Not Feasible

It is not feasible for the Port to plan on securing all moorings of vessels in Cap Sante Marina; however, the Port does have the capability to use its AlertSense system to disseminate protective action recommendations that include securing moorings to private vessel owners. These recommendations would depend on expected wave arrival times for the tsunami to preserve life safety and would need to be done in coordination with evacuation efforts from waterfront areas. The Port does own one small vessel that is always securely moored and would not be a priority to check during a tsunami incident.

It is recommended that the Port work with partner agencies, including the Skagit County DEM and WA EMD, to develop scenario-specific canned messaging for alert dissemination. The Port should also consider including the importance of proper mooring in public education materials and other communications so their stakeholders understand how taking a few extra seconds to secure their vessels can help save lives and property. WA EMD will continue working with the Port to provide tsunami response recommendations for boaters; the Port has disseminated over 700 Tsunami Boater's Guides to their users.

Remove Small Vessels from the Water

Feasibility for the Port of Anacortes: Not Feasible

There is one small response vessel that is owned by the Port of Anacortes in Cap Sante Marina. Due to the size and capability of this vessel, it would not be a priority to remove from the water prior to tsunami wave arrival.

There is a public small boat hoist and trailer boat launch in Cap Sante Marina that require purchase or annual passes for use. It recommended that these facilities are closed and associated staff evacuated prior to wave arrival, thus limiting access to prioritize public safety. As with other recommended response actions in this strategy, the Port can help educate vessel owners of recommended protective actions they can take to protect themselves, their crew, and their vessels during tsunamis, including securing their moorage and heading inland to high ground.

Remove Buoyant Assets Out of and Away from the Water

Feasibility for the Port of Anacortes: Not Feasible

Currently, the Port does not have any buoyant assets which fit this recommendation. However, the Port should consider providing education to their tenants about securing their buoyant assets so items outside the Port's control can also be secured. These public education efforts can be completed in tandem with recommendations provided by WA EMD to complement existing educational resources.

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

Feasibility for the Port of Anacortes: Not feasible

For the Port of Anacortes, the Puget Sound Pilots handle the movement of large ships, including oil tankers and cargo ships, and would make the decision whether to bring vessels into or out of the Port. These pilots should be trained on what to do to protect vessels during a tsunami. The Coast Guard can restrict the entrance of recreational traffic into or out of the Port, which they do for hazardous bar conditions. Unless it is included in an emergency declaration by the Governor, or possibly the County, no one can prevent commercial craft that do not require a pilot on board to enter or leave The Port of Anacortes.

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

Section 5: Tsunami Mitigation Guidance

Mitigation actions represent a proactive and strategic approach aimed at diminishing the potential risks posed by natural disasters before they occur. These interventions are vital in safeguarding both lives and property, necessitating a substantial investment of time, resources, and expertise. For tsunamis, as with all natural hazards, the critical role of mitigation actions becomes evident in their potential to significantly reduce the impact on maritime infrastructure. Examples of such actions include fortifying cleats and moorings, as well as installing sturdier or taller dock piles.

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

Tsunami Mitigation Actions

We present an array of potential tsunami mitigation actions below, drawing inspiration from successful implementations in other states. This compilation highlights the practicality, implementation nuances, and overall impact of these mitigation strategies. Covering an expansive range from structural enhancements to community engagement initiatives, each description is crafted to empower communities and key decision-makers with a comprehensive understanding of the diverse measures available for minimizing the impact of tsunamis and fortifying maritime infrastructure against potential risks. By delving into the specifics of each mitigation action, this section fosters informed decision-making and proactive planning to enhance resilience in the face of potential tsunami events.

Install Tsunami Signs

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

Installing tsunami signs is the easiest and most cost-effective mitigation action that a port, harbor, or marina can take to reduce tsunami injuries and casualties. Signage can help educate harbor users of the tsunami danger in the area and direct individuals to higher ground during an evacuation. Signs are generally cheap, installation is easy, and upkeep is minimal. Signage posted along roadways and trails alerts people that they are entering or leaving a tsunami inundation zone so they know of the need to evacuate if a tsunami warning is issued. Signage indicating the location and direction of evacuation routes helps people find and follow established evacuation routes quickly during an evacuation. Each state and territory uses standardized wayfinding signage to designate the extent of inundation areas as well as to designate and define evacuation routes. Additionally, more informational signage can be created to educate and inform people of anticipated tsunami inundation extent, evacuation route maps, and general tsunami information. Many states, counties, and cities that face tsunami danger have built informational kiosks to inform the public of tsunami dangers, such as the evacuation kiosk shown in figure 40.

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

Figure 41: Dock damage in Marina Chiapas after the 2017 earthquake and tsunami. (Maria Teresa Ramirez-Herrera, 2017)

Structurally, the pilings are one of the most important components of a dock. The pilings act as the dock's foundation, keeping the structure attached to the sea floor while allowing vertical movement as water levels change with waves or tides. Tsunami inundation has the potential to float docks off the top of the pilings, leaving them unattached and floating freely (Figure 41). The strong currents caused by tsunamis can also pull pilings from the ground through scouring or drag on the docks and vessels attached to them. Pilings that are pulled loose also lead to unattached docks floating free in the dangerous waves. Untethered, freely floating docks pose a danger in a tsunami, essentially becoming massive pieces of debris moved by the waves, possibly with vessels still attached to them. To help ensure docks remain attached to the sea floor during a tsunami, ports and harbors may choose to increase the size and stability of the pilings. Installing pilings taller than the expected potential inundation levels will help ensure docks do not float off the top of the pilings during a tsunami. Thicker pilings will resist the shearing forces from the extreme drag of the tsunami waves much better than thinner ones. Installing pilings deeper into the sediment of the sea floor can help them remain foundationally solid, more resistant to scouring, and keep them from pulling out of the soil.

Reduce Exposure of Petroleum/Chemical Facilities and Storage

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

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

Strengthen Cleats and Single Point Moorings

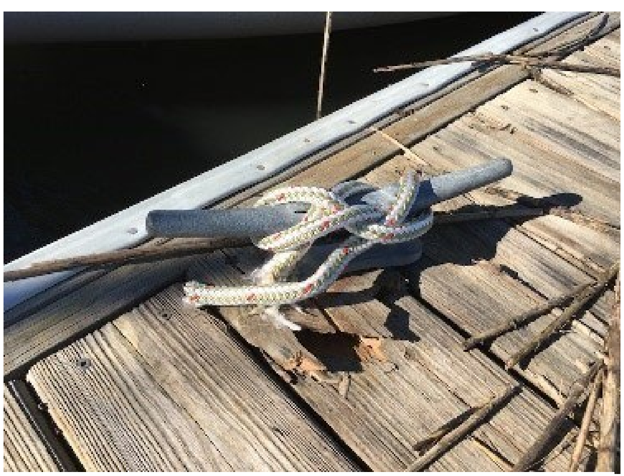

Figure 42: Cleat moored to vessel ripped away from dock.

The cleats and mooring points used to anchor vessels to docks need to withstand extreme forces during a tsunami. Vessels that are pulled free from their moorings during a tsunami quickly become part of the debris moving in the water, potentially destroying other vessels and infrastructure. Cleats and mooring points that are poorly installed or are of insufficient size for the vessels moored to them will not be able to withstand the forces exerted on them during a tsunami and could be ripped free (Figure 42). Lag bolts attaching cleats can snap or be pulled free from the dock structure; worn and rusty cleats can break off or bend, releasing lines. To ensure that the mooring points remain secure even in extreme scenarios, cleats need to be rated strong enough to hold not just the weight of the vessels they secure, but also withstand the additional forces from the drag on those vessels due to the extreme currents of a tsunami. Such cleats and moorings should be secured to the dock structure with high tensile bolts and a backing plate so pulling forces are spread over a larger surface area.

Improve Movement of Dock Along Dock/Pilings

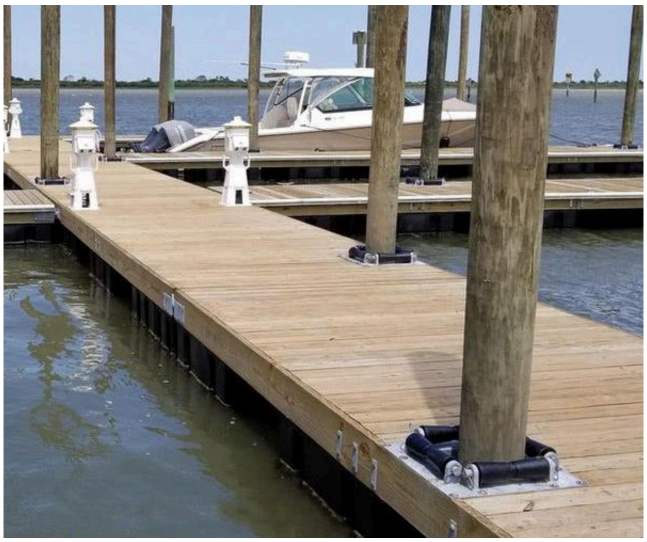

Figure 43: Floating docks with square pile guides for each piling (americanmuscledocks.com/products/square-pile-guide-poly).

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 'jam' against the pilings, leaving the dock unable to float up with the water. When docks get stuck on the piles, the water level can quickly overtop the dock surface, causing major damage. Some hardware used to connect docks with pilings, such as simple metal hoops with little space between the dock hardware and piling, can be more prone to binding. As docks lift rapidly on one side, the other side can become wedged against the piling at an angle. The force of the water against the dock surface can bend these hoops, trapping the dock even more, or can cause the connection hardware to break, leaving the dock unattached to the piling and allowing it to float freely and become debris. Dock connections to piles that run through a hole in the dock surface are less likely to bind or break, and utilization of guide wheels or rollers helps to avoid binding issues and promote smooth movement even more (Figure 43).

Acquire Equipment/Assets to Assist Response Activities

Post-tsunami response will be a complicated effort involving many personnel and equipment. Vessels will be needed to search the water for survivors or casualties, as well as move damaged vessels, broken or detached docks, and other large debris in the area. Fireboats and other firefighting equipment will be needed to extinguish any fires that start among vessels, facilities, or on floating debris. Cranes may be needed to hoist and move large debris either in the water or elsewhere on the port property. Other equipment may also be required such as loaders, bulldozers, or other earth moving equipment to clear debris and allow access to all port property. Large ports and marinas may already have some of this equipment on site; smaller ports may have less equipment or may rely on equipment owned or operated by other entities. Regardless, response will require equipment, and the more of that equipment that is either owned by or prearranged for use by the port or marina, the faster the response can begin and clean up can start. If a port does not have equipment or the means to purchase it, they should consider developing a response plan that addresses this issue, including agreements with local entities to rent, borrow, or have use of any equipment that would be needed to respond after a tsunami in their port.

Improve Floatation Portions of Docks

Figure 44: Docks on floating Styrofoam blocks.

The rapid onset of tsunami waves can over-top docks, causing them to sink and break apart if the docks are not sufficiently buoyant. It may appear that all docks have sufficient floatation portions under them if they are floating and rise and fall with the tides and waves. However, certain styles and materials of floating dock structures are in fact much more buoyant than others. Many docks are 'pontoon' style, where tubes of buoyant materials (sometimes filled with foam) run in a parallel track with a platform built on top. Another common dock construction technique is to use solid floating 'blocks' either at the ends of the dock structure or at widely spaced distances along the entire length (Figure 44). These styles, while common, will not prove as buoyant as docks with a floatation section that spans the entire underside of the dock area. The most buoyant docks are built on top of sturdy, sealed 'blocks' made from High Density Polyethylene (a strong, impact resistant plastic) filled with buoyant foam such as Expanded Polystyrene (like Styrofoam) which spans the entire dock width and length (Figure 45). The increased buoyancy of full floatation docks will do best at handling the extremely fast changes in water depths that accompany tsunami waves.

Figure 45: Docks built on full flotation.

Increase Flexibility of Interconnected Docks and Dock Fingers

Figure 46: Broken docks in Crescent City, CA from the 2006 Kuril earthquake (USGS 2006).

The rapidly changing water levels, extreme waves, and unpredictable currents associated with tsunamis will test the flexibility of any dock system, including dock fingers. This can also be true for large storm surges and swells, bending or breaking them at joints connecting dock sections, as in Figure 46, and where dock fingers are attached. The refracting waves of a tsunami move docks in both horizontal and vertical directions in ways docks may not have been subjected to prior to the event. Increasing the amount of movement between sections of docks at their joining points can help ensure docks remain connected and intact after tsunami waves recede. Increasing flexibility along the joints of dock sections and their fingers can involve lengthening gaps between the sections to allow for increased movement or utilizing more flexible types of hardware to make the attachments resistant to stress and fracturing.

Debris Deflection Booms to Protect Docks

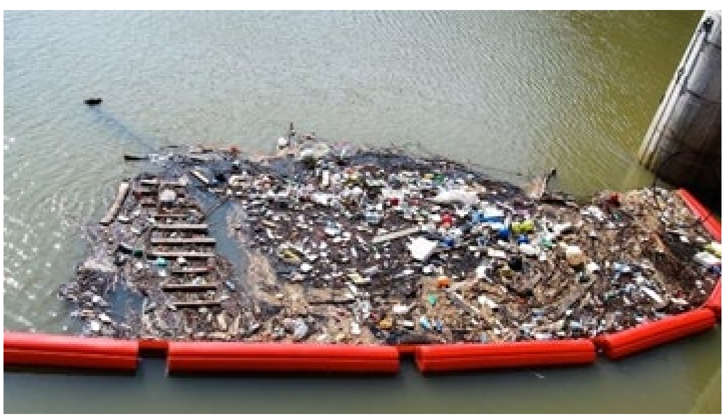

Figure 17: Debris deflection boom (Worthington Waterway Barriers).

Debris deflection booms are installed in harbors to protect dock structures from damage caused by floating debris. Booms are installed between the open water and the docks to deflect any floating debris and prevent it from striking dock structures or moored vessels. Debris deflection booms are typically made from floating interconnected pieces of formed plastic filled with foam (much like smaller dock floats) to ensure they do not sink, as shown in Figure 47. These individual floats are strung together with a cable and attached on each end to a foundational piling that allows the floats to rise and fall with tides and waves. Debris deflection booms would likely be overwhelmed by large local tsunami waves carrying immense amounts of debris but would function well to protect docks from smaller tsunami waves and lighter amounts of debris from a distant tsunami. Even a partial reduction in the amount of debris carried on tsunami waves would help reduce damage from collisions between debris and vessels or dock structures. Debris booms need to be able to rise much higher than typical tidal changes to accommodate the extra rise of water from tsunami waves so they do not become over topped, eliminating their effectiveness.

Move Docks and Assets Away from High Hazard Zones

Once a port has been able to identify the areas that are more likely to experience significant tsunami hazards, they can consider relocating port infrastructure away from these areas. Docks and vessels in the highest hazard areas are at the most risk of damage or destruction during a tsunami. Moving this infrastructure away from high hazard areas and into areas that are anticipated to face a lower hazard risk can help save infrastructure and vessels from becoming broken or detached. Moving docks and infrastructure in a port or harbor is a substantial undertaking involving careful planning. New construction may be required shoreside to reroute walkways or build new shore anchoring systems. Old pilings would need removal and, if of sufficient size and strength, repositioning in the new location, or replacement with piles of greater height, strength, or thickness. Despite all the work involved, if a port has the space and ability to reconfigure the layout of a harbor area to eliminate docks from high hazard zones, there would be a large benefit in the reduction of damaged or destroyed vessels and infrastructure if a tsunami were to occur.

Fortify and Armor Breakwaters

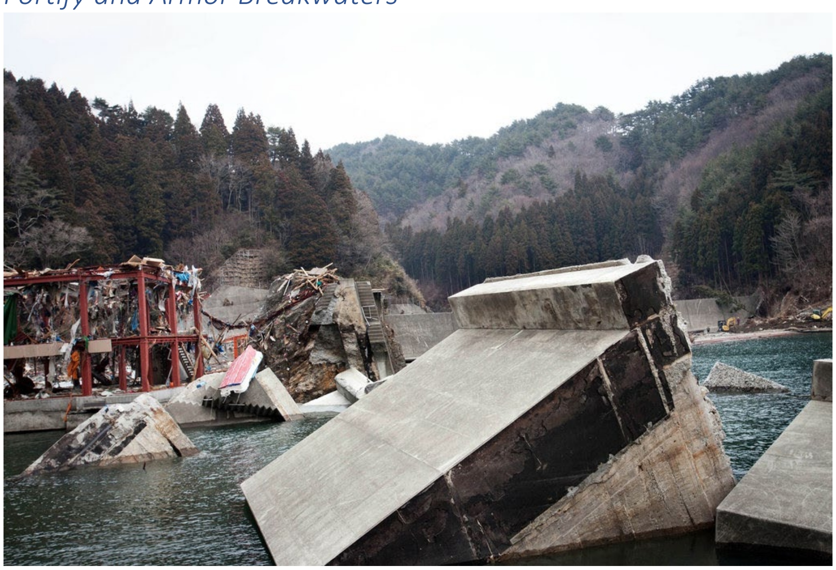

Figure 48: The Kamaishi breakwater, which failed during the 2011 Japanese tsunami (NY Times)

Breakwaters are designed to absorb and deflect strong wave action to protect ships and vessels from rough seas. Unless built to extreme heights, breakwaters are unlikely to block large tsunami waves. The waves would likely overtop the structure, allowing inundation to enter the normally protected area. The strong waves and currents from a tsunami could also cause extreme scouring on infrastructure like breakwaters. The wave action can remove the soil that acts as the foundation of the structure and could even strip away sections of the breakwater itself. Scouring and damage during a tsunami could cause the breakwater to fail, as pictured in Figure 48, allowing even more water to flow into the area. Sudden gaps in the breakwater can also create new, unpredictable, and dangerous currents. Any damage to breakwaters will also need to be repaired post-tsunami, and if damage is severe enough could require full replacement of the structures at considerable time and cost.

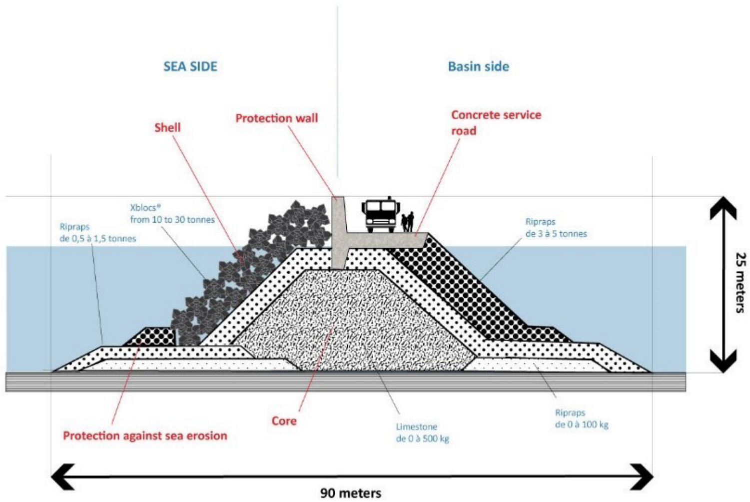

Figure 49: Diagram of fortified breakwater.

The concept behind armoring or fortifying breakwaters is simple; the entire structure is further reinforced to make it stronger, thicker, and sturdier. These enhancements are made to create more resilient structures better able to withstand the effects of a tsunami. Fortification implies strengthening the entire structure through the addition of material like rubble or concrete, increasing the size and strength of the foundation, and overall creating a larger and more sturdy structure as seen in Figure 49. Armoring implies covering the seaside of the breakwater with additional materials to help in strengthening the structure. Armoring can be done with actual rock like rubble or using wave dissipating blocks, large pre-formed concrete blocks built to be placed in an interlocking pattern less likely to break loose in strong wave and current action as shown in Figure 50.

Figure 50: Photo of fortified breakwater off marina.

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

Construct Breakwaters Farther Away from the Port

Figure 51: Breakwater protecting the harbor of Hilo, Hawaii ([Big Island Gazette](#))

Breakwaters confine and shelter harbors, providing protection from storm surges, strong waves, and ordinary floating debris. During a tsunami, however, these same breakwaters constrict rapidly changing water levels and current movements. Tsunami effects are amplified in confined and restricted areas, the smaller space forcing the currents to move faster, and refracting waves are created as the water sloshes within the enclosed basin. Constructing breakwaters farther from harbors allows more unrestricted movement of the water during an extreme tsunami (Figure 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 straight.

Deepen or Dredge Channels Near High Hazard Zones

The effects of a tsunami wave will always be strongest and most pronounced in shallower waters. Just as the wave rises higher as it enters shallower waters, pushing the water further onto dry land, the other effects are similarly more pronounced in locations where the depth is less. In harbor areas, scientific mapping and modeling can identify specific locations where tsunami hazards are highest. Deepening these locations through dredging or other means will not eliminate the hazards but can help lessen their effects. Dredging or otherwise deepening channels is a complicated process that requires significant inputs of time and money. Given the benefit from deepening channels will only alleviate some of the effects of the tsunami hazard, it is most likely not worthwhile as a standalone action. However, sedimentation builds up over time and eventually all harbors, ports, and channels require dredging for maintenance purposes. Ports could use this time of regular maintenance to utilize hazard maps, determine the areas of high hazard, and deepen them as much as feasible.

Widen Size of Harbor Entrance to Prevent Jetting

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

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

Construct Floodgates

Figure 52: Floodgates in Fudai, Japan stand tall after the 2011 tsunami. (NBC News)

The construction of floodgates has proven successful in several locations to lessen or eliminate inundation from tsunami waves. While the largest and most powerful tsunamis can overtop or otherwise breech floodgates, they have proven extremely effective during smaller tsunamis, and even during large tsunamis in locations with less inundation. Japan has constructed several massive floodgates that proved effective against tsunami waves, like the floodgate pictured in Figure 52.

Construction of floodgates is likely the most complicated and labor and time intensive mitigation project listed here. Additionally, there are potential issues with installing floodgates: they can disrupt natural tidal movements; they require a massive physical footprint; they need to be operable after a major earthquake; and they need to be able to be closed before the waves arrive to be effective for tsunami mitigation. Floodgates are most effective when waterways have a narrow entrance to a bay, port, or harbor, allowing one set of gates to protect the entire area.

Feasibility of Tsunami Mitigation Guidance for the Port of Anacortes

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

The 'Feasible' designation implies that the mitigation action is deemed practical and implementable within the context of the local geography, infrastructure, and resources. Actions categorized as 'Needs Review' may require further scrutiny and adaptation to address specific considerations unique to the Port of Anacortes and the Guemes Channel area. Conversely, mitigation actions labeled as 'Not Feasible' were deemed as inapplicable, too challenging to execute, or may pose inherent risks that outweigh their potential benefits in the context of life safety and protecting property and were not included or expanded on.

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

Additionally, under each mitigation action, information is organized into three key sections: Mitigation Activity, Agency Responsible, and Funding Options. This structure helps provide a clear understanding of what needs to be done, who is responsible for executing the action, and how it will be funded. This format aligns with the approach outlined in the previous Skagit County Department of Emergency Management (DEM) Hazard Mitigation Plan. In the next update of the Skagit County DEM's Hazard Mitigation Plan, the Port of Anacortes can incorporate and refine these suggestions as needed. Furthermore, it can advocate for the inclusion of the Port of Anacortes Tsunami Maritime Response and Mitigation Strategy in the Plan.

Activity	**Agency Responsible**	**Funding Options**
This section outlines the specific action that needs to be taken to mitigate the risk	Here, the primary entity responsible for carrying out the mitigation activity is identified and time period for completion is outlined.	This section addresses how the mitigation activity will be funded.

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

Install Tsunami Signage

Feasibility of Mitigation Action: Feasible

This is an easy action for the Port of Anacortes to address and there is a high need for signage near Cap Sante Marina where there is heavy recreational vessel usage. Skagit County Emergency Management and the Port of Anacortes plan to work with Washington Emergency Management Division in the future on the placement of wayfinding signage (tsunami evacuation route, tsunami arrows, evacuation route information) and informational signage educating Port users about tsunami risk, alerts, and evacuation information.

There currently is no educational signage in the City of Anacortes and very limited wayfinding signage. As part of a larger statewide tsunami wayfinding project, Washington Emergency Management division inventoried locations of existing signage in Anacortes and provided recommendations for placement of additional signage. The City and Skagit County Department of Emergency Management will work with WA EMD to provide and install this signage.

While it may be expensive, investigating options that employ the use of electronic signage could be beneficial where information about local emergencies, like tsunami warnings, could be updated and disseminated quickly. Information about recommended evacuation routes, protective actions to take, and other general information could be displayed as well.

Activity	Agency Responsible	Funding Options
Install tsunami signage in and around Cap Sante Marina, Curtis Wharf, Pier 1, and Pier 2. This includes an informational kiosk about earthquake and tsunami safety for visitors and marina users.	Port of Anacortes, Skagit County EMD, and City of Anacortes- Short term within 1 year to procure signage and work with WA EMD.	Signage may be available via WA EMD at no cost; if not, it would need to be procured by working with the WA EMD tsunami program to explore a variety of funding sources including grant funds, federal, state, and local funds.

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

Feasibility of Mitigation Action: Feasible

The Port of Anacortes has hundreds of wood and concrete monolithic pilings on both the Port side as well throughout Cap Sante Marina. On the northern side of Cap Sante Marina the pilings in docks G through Q are made of timber and are composed of much of the original 1980s materials, aside from ongoing replacement and maintenance. Starting in 2005, most of the wood pilings for Docks A through F have been replaced with concrete monolithic pilings on the southern end of the Marina. While it is feasible to replace wood pilings with concrete monolithic pilings in the northern half of the Marina for Docks G through Q over time, it would be a cost prohibitive process that may supersede any tsunami mitigation potential. Additionally, modeled tsunami current speeds are much higher in the southern portion of Cap Sante Marina where most of the pilings are already replaced with concrete monolithic ones for Docks A through F (refer to figures 21 and 22). It would be more cost effective to determine if the end ties near areas of potential high current speeds are strong enough to withstand those current speeds.

It is important to note that the Port's administration offices are built on wood pilings and could be susceptible to damage from high current speeds, wave height, and debris. The Port should do an assessment of the stability of these pilings, along with the stability of the rest of the infrastructure to determine if retrofits or replacement of pilings would be necessary for overall structural integrity during tsunamis.

There is concern about the current height of the pilings throughout Cap Sante Marina not being high enough, even for large storms and king tides. Currently, most of the pilings sit at about 5 feet above MHW during normal conditions; during previous king tides, only the piling caps were visible on some pilings. Looking at both a Cascadia and Alaska tsunami scenario, raising the piling heights could help mitigate the potential for the pilings to be overtopped by tsunamis, while also accounting for sea level rise, storm surge, and king tide potential. While this option would be an expensive one, it could be considered in future upgrade and replacement projects.

Figure 53: Map of Cap Sante Marina showing location of docks, slips, and other information intended for Marina tenants, users, and visitors. (Port of Anacortes, 2023)

Activity	Agency Responsible	Funding Options
Conduct a comprehensive assessment of the stability of wood pilings supporting the Port's administration offices, evaluating susceptibility to damage from high current speeds, wave height, and debris. Based on the assessment findings, implement retrofits or replacement of pilings as necessary to ensure the overall structural integrity and resilience of the Port infrastructure against tsunami impacts.	Port of Anacortes Engineering and maintenance staff will be part of the assessment process, potentially working with contractors for implementation. Medium term project assessment and implementation could be within a 3–5-year period.	Funding for the assessment and retrofitting/replacement of pilings will be sourced from a combination of the Port of Anacortes' capital improvement budget, federal grants for hazard mitigation projects, and potentially federal disaster relief funds allocated for enhancing infrastructure resilience against sea level rise, storm events, and tsunamis.

Implement a plan to raise/retrofit the height of pilings throughout Cap Sante Marina to mitigate the risk of overtopping during tsunamis, while also addressing concerns related to sea level rise, storm surge, and king tide potential. This initiative will involve assessing the current piling heights, determining the necessary height increase, and executing retrofitting or replacement projects accordingly.	Port of Anacortes Engineering and maintenance staff will be part of the assessment process, potentially working with contractors for implementation. Medium term project assessment and implementation could be within a 3–5-year period.	Funding for the elevation/retrofit of pilings will be sought through a combination of the Port of Anacortes' capital improvement budget, federal grants for hazard mitigation projects, and potentially federal disaster relief funds allocated for enhancing infrastructure resilience against sea level rise, storm events, and tsunamis. Additionally, exploring opportunities for federal funding through hazard mitigation programs or disaster resilience initiatives will be pursued to offset the costs associated with this critical infrastructure enhancement.

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

Feasibility of Mitigation Action: Feasible

On the northern side of Cap Sante Marina, docks G through Q were originally constructed in the 1980s and the through bolts that connect the docks together often break, requiring regular maintenance and repair. When the through bolts break, this causes the docks to wobble and compromises the resilience of the interconnected dock system. Since 2005, Docks A-F in the southern part of the Marina have been recently replaced and modernized.

Modeled tsunami current speeds are much higher in the southern portion of Cap Sante Marina where most of the docks have already been replaced and modernized. With this said, more discussion on capability and analysis of these docks to withstand tsunami wave momentum flux and load can be assessed, including whether improving flotation of the docks would be feasible as well. An assessment of the entire marina using the tsunami modeling from this document is recommended, including leveraging a list of historic problem areas needing ongoing and repeated replacement.

Activity	Agency Responsible	Funding Options
Conduct a comprehensive assessment of the structural integrity and resilience of docks G through Q on the northern side of Cap Sante Marina, focusing on the through bolts that frequently break and compromise the interconnected dock system and evaluating floatation alternatives. Utilize tsunami modeling data to evaluate the capability of the docks to withstand tsunami wave momentum flux and load, particularly in comparison to the southern portion of the marina where docks have been replaced.	Port of Anacortes Engineering and maintenance staff will be part of the assessment process, potentially working with maritime contractors. As needed, engineers and contractors could work with the Washington Geological Survey regarding understanding the tsunami modeling data featured in the Technical Report attached to this Tsunami Maritime Response and Mitigation Strategy. Short Term project assessment could be within 1–2-year period.	Funding for this assessment could be provided from a combination of the Port of Anacortes' capital improvement budget, federal grants for hazard mitigation projects, and potentially federal disaster relief funds allocated for enhancing infrastructure resilience against sea level rise, storm events, and tsunamis.

Strengthen Cleats and Single Point Moorings

Feasibility of Mitigation Action: Needs Review

The terminal has large-scale industrial-sized cleats, which are more stable and less likely to break under stress. However, the cleats in Cap Sante Marina are more of a concern as the wooden docks and cleats are not as sturdy, especially on the northern end of the Marina. Docks G through Q were originally constructed in the 1980s and the cleats often pull from the wood or break, requiring regular maintenance and repair. Currently there are plans to make the anchoring infrastructure for the cleats on T-Dock strong enough to withstand breaking loose with high winds or current speeds. While there are no immediate plans to replace the wooden docks or cleats on the northern docks, reconditioning conversations are currently under way, though this is likely a few years out. Concrete docks like the ones on the south end of Cap Santer Marina, on the other hand, are through-bolted, which makes them more stable than they were previously. Most recently, Pier 1 had cleats replaced in 2020 and Curtis Wharf's cleats were replaced in 2019.

Given current concerns regarding the repeated replacement and repair of cleats on the northern end of Cap Sante Marina, compounded by the potential impact of tsunami waves further stressing this infrastructure, a replacement strategy is recommended. While plans are underway to reinforce the anchoring infrastructure for cleats on T-Dock to withstand high winds and currents, the ongoing conversation about reconditioning wooden docks and cleats underscores the need for a proactive approach. Considering the increased stability and durability demonstrated by recent cleat replacements on Pier 1 and Curtis Wharf, it may be prudent to explore options for upgrading the northern Cap Sante Marina docks to concrete or implementing similarly resilient cleats designed for smaller vessels.

Activity	Agency Responsible	Funding Options
Initiate a comprehensive assessment of the cleats and anchoring infrastructure on the northern docks of Cap Sante Marina (Docks G-Q) to identify vulnerabilities and prioritize replacement or retrofitting measures. Explore options for upgrading to concrete docks or implementing resilient cleats designed for smaller vessels to enhance stability and durability.	Port of Anacortes Engineering and maintenance staff will be part of the assessment process, potentially working with maritime contractors. As needed, engineers and contractors could work with the Washington Geological Survey regarding understanding the tsunami modeling data featured in the Technical Report attached to the Tsunami Maritime Response and Mitigation Strategy. Medium term project assessment, procurement, and implementation could be within a 3–5-year period.	Funding for this assessment could be provided from a combination of the Port of Anacortes' capital improvement budget, federal grants for hazard mitigation projects, and potentially federal disaster relief funds allocated for enhancing infrastructure resilience against sea level rise, storm events, and tsunamis.

Fortify and Armor Breakwaters

Feasibility of Mitigation Action: Needs Review

The central core breakwater entering Cap Sante Marina may not withstand the current speeds generated by both Alaskan and Cascadia tsunamis. The United States Army Corps of Engineers (USACE) owns and maintains a breakwater, while the Port owns and maintains both southern breakwaters. Currently not much is known about the USACE-maintained breakwater, including when it was constructed, how it is maintained, or its integrity. The Port of Anacortes should work on developing a relationship with USACE and their engineers to learn more about the breakwater and potential future planning around its maintenance and upkeep. This could prove beneficial to USACE as well so they can incorporate tsunami modeling into these considerations.

While this mitigation measure would not be initiated at the local level, but at the federal level with USACE, advocating for an assessment of the USACE-owned breakwater for its resilience against potential tsunami wave action would be beneficial. This assessment could lead to future strengthening and armoring efforts that could prove effective in reducing wave action within Cap Sante Marina.

Activity	Agency Responsible	Funding Options
Initiate a comprehensive assessment of the central core breakwater owned and maintained by the United States Army Corps of Engineers (USACE) to evaluate its resilience against potential tsunami wave action. Consider options such as fortification or armoring of the breakwater structure to enhance its strength and durability, thereby reducing the risk of damage and failure during extreme wave events.	The Port of Anacortes, in collaboration with the United States Army Corps of Engineers (USACE) and marine engineering consultants, will lead the assessment and implementation of mitigation measures for the central core breakwater. Long Term project may take 5+ years for assessment and building relationship with USACE since this is not a Port owned asset.	Since this is owned by USACE, funding for the assessment and potential fortification or armoring of the breakwater would be provided by USACE with advocacy from the Port and leverage with federal grants. Leveraging resources and expertise from USACE's existing programs and initiatives may also offset costs associated with engineering, environmental assessment, and construction processes.

Reduce Exposure of Petroleum/Chemical Facilities and Storage

Feasibility of Mitigation Action: Needs Review

The Port of Anacortes should conduct a thorough review, assessment, and cataloging of chemical and petroleum storage facilities located on Port property. This assessment will involve overlaying the storage locations with areas of potential inundation from both Alaska and Cascadia-modeled tsunamis. If there is an overlap between these areas, the Port should consider relocating the assets to higher ground. Additionally, feasible alternative locations for storage should be identified, assessing their capability to support the required functionality if relocation is possible. For assets that cannot be relocated, options such as elevation or the development of Standard Operating Procedures (SOPs) to reduce exposure and spill potential should be explored, such as tank capping or valve closure. These SOPs must be regularly reviewed, tested, and updated to ensure effectiveness, especially with the acquisition of additional chemical storage by the Port. Privately owned vessels and facilities within the Port may also contain hazardous materials, and outreach efforts should be undertaken to inform users, boaters, and tenants about personal response actions to secure these materials.

The structural integrity of the fuel dock, situated at the southeastern tip of Cap Sante Marina, is of particular concern due to modeled maximum current speeds exceeding 9 knots for both Cascadia and Alaska scenarios (Figure 21 and 22). Given the critical role of the fuel dock in ongoing marina operations, as well as its importance for fuel vessels used in emergency response and spill recovery, it is recommended that the fuel dock be either relocated or retrofitted to withstand potentially hazardous tsunami current conditions. A detailed assessment is necessary to evaluate multiple options and the feasibility of such actions, which could help mitigate petroleum spillage and ensure uninterrupted access to the primary fuel source within the Marina following a disaster.

Activity	Agency Responsible	Funding Options
Conduct a thorough assessment of chemical and petroleum storage facilities owned by the Port of Anacortes to identify vulnerabilities and prioritize spill mitigation measures. This assessment will involve site inspections, hazard mapping, and risk analysis to determine the most effective strategies for reducing exposure and spill potential during tsunamis, and other natural hazards.	Port of Anacortes engineers, in collaboration with environmental consultants, will lead the assessment of chemical and petroleum storage facilities. This would be considered a medium-term project, expected to take 3-5 years. The initial cataloging of chemical and petroleum assets will have a shorter completion timeframe, while conducting risk analysis and determining effective strategies for exposure and spill reduction using tsunami modeling will require more time.	Funding for the assessment of chemical and petroleum storage facilities may be allocated from the Port of Anacortes budget and supplemented by grants from federal agencies specializing in disaster preparedness and hazardous materials management.

Acquire Equipment/Assets to Assist in Response Activities

Feasibility of Mitigation Action: Needs Review

Assets that are currently owned by the Port of Anacortes and the City of Anacortes could potentially be used for tsunami response at the Port, if necessary, but further review of available assets and procedures would need to be established. Currently, there is one small Port owned vessel that can be used for emergency response. The Port does hold contracts with spill response teams to assist in spill cleanup of chemicals and oil.

Outside of these existing contracts for oil spill response and clean up, The Port does have strong relationships with private tenants and companies in the community that could be leveraged in tsunami response with established MOUs and organization. With these strong community partnerships, the Port may consider working with the private sector and public on mapping existing vessels and assets that could be used in response like the City of Bainbridge Island's work with developing the Bainbridge Island Flotilla. The Bainbridge Island Flotilla serves as a critical part of the City of Bainbridge Island's emergency planning and operations and consists of volunteered recreational and commercial vessels, captains, and crew members. Flotilla members train together with emergency professionals to provide vital transportation over water to emergency responders, citizens, and critical patients in need of transport to definitive care. More about the Bainbridge Island Flotilla can be learned about here. By creating an asset list of potential response vessels, emergency managers and responders could have a critical understanding of what might be available to use during emergencies of all kinds given appropriate MOUs and relationship building with the private sector and public.

Activity	**Agency Responsible**	**Funding Options**
Establish Tsunami Response Asset Inventory and Mobilization Plan	Skagit County Department of Emergency Management and the Port of Anacortes should leverage local CERT programs, marina committees, businesses, and yacht clubs to gauge interest and volunteers. Possible collaboration with City of Bainbridge Emergency Management and Flotilla volunteers to gather lesson learned. Short Term, less than 1 year	This could be done with limited FTE time and volunteer coordination. Could allocate resources from the Port of Anacortes and Skagit County Department of Emergency Management budgets, supplemented by grants from federal agencies specializing in disaster preparedness and hazardous materials management.

Section 6: Conclusion and Next Steps

The threat of tsunamis to the maritime community of the Guemes Channel and the Port of Anacortes is significant, with potential damage to infrastructure, vessels, and hazardous conditions for those on the water, shoreline, and within the inundation zone. This damage could render the Port inoperable for an extended period, disrupting vital fishing and maritime tourism activities and causing substantial revenue loss for the area. The restoration of the Port to pre-event conditions could entail significant time, money, and effort.

Notably, variations in wave amplitudes and current speeds, particularly from distant source tsunamis originating in Alaska, could exceed previous expectations along the inner coast of Washington. Furthermore, the modeled drawdown of water in the Guemes Channel following a Cascadia earthquake may commence earlier than assumed, with a one-foot decrease as soon as 50 minutes after the quake's onset, despite the initial one-foot rise taking 1 hour and 45 minutes to reach the channel. Monitoring wave arrival over time throughout the Guemes Channel will provide the Skagit County Department of Emergency Management (Skagit County DEM) and the Port with a better understanding of specific emergency response needs and capabilities.

This underscores the critical importance of assessing and comprehending the hazard and risk associated with tsunamis. With this knowledge, measures can be implemented to enhance response capabilities and mitigate risks. Such actions can potentially save lives, enhance the Port's resilience, and expedite its recovery, thereby reinstating a vital component of the maritime infrastructure and economy. Moreover, they can bolster the Port's resilience against more frequent hazards like extreme storms, unusually high tides (i.e., King tides), sea-level rise due to climate change, and floods. Given the tsunami risk and the Port's significance to both the maritime community and the local economy, every effort to mitigate this risk is a stride toward fostering a more resilient community.

Moving forward, the Port can adopt measures and engage in both mitigation and response actions to enhance its resilience and ensure the safety of its customers, tenants, and the public in the event of a tsunami. While some of these actions are relatively straightforward and manageable, others may necessitate more time, planning, and external assistance.

Recommended Response Actions

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

Here's a summary of the response activities recommended for the Port of Anacortes and Skagit County DEM, categorized by feasibility and the need for review:

Feasible Response Activities:

- **Shut Down Port Infrastructure Before Tsunami Arrives:** Develop SOPs for shutting off power, water, and fuel lines upon receiving a tsunami alert, while coordinating with relevant stakeholders for efficient communication and shutdown procedures.
- **Evacuate Public/Vehicles from Waterfront Areas:** Utilize designated evacuation areas and alert systems managed by the City of Anacortes and Skagit County DEM, considering challenges like ferry evacuation and transportation disruptions.
- **Personal Floatation Devices/Vests for Port Staff:** Emphasize the importance of wearing personal floatation devices for all Port staff during tsunami responses.
- **Informing and Coordinating with Key First Responders During a Tsunami:** Enhance communication protocols with Skagit County DEM and other agencies for efficient coordination and information sharing during tsunami incidents. This can be accomplished by Skagit County DEM initiating their own local coordination conference call during tsunamis.

Response Activities Needing Review:

- **Remove or Secure Hazardous Materials Used or Owned by Port:** Update emergency response plans and SOPs for securing chemical storage and runoff systems to prevent spills during tsunamis.
- **Identify Boat Owners/Individuals Who Live Aboard Vessels and Establish Notification Processes:** Ensure accurate communication channels and educate boat owners on emergency procedures, potentially utilizing registration processes for alerts.
- **Activate Incident Command at Evacuation Sites:** Explore options for incident command locations outside inundation zones and train Port staff in ICS procedures for effective response coordination.
- **Move Vessels Out of the Port:** Coordinate with agencies and vessel operators to assess the feasibility of relocating vessels, considering logistical challenges and communication with relevant stakeholders.
- **Restrict Traffic Entering the Port by Land and Aid in Traffic Evacuation:** Collaborate with the City and other agencies to establish traffic management plans for shoreline evacuations, ensuring staff awareness and regular drills.
- **Activate Mutual Aid System as Necessary:** Develop a Skagit County Tsunami Action Plan to determine mutual aid needs and train Port staff in requesting and utilizing mutual aid resources effectively.
- **Reposition Ships Within the Port:** Evaluate the potential for repositioning vessels within the Port to mitigate damage, coordinating with maritime authorities and enhancing communication with vessel operators.
- **Stage Emergency Equipment Outside Affected Area:** Assess the feasibility of staging emergency equipment outside inundation zones, collaborating with stakeholders and establishing SOPs for equipment relocation.

- **Pre-Identify Personnel to Assist in Rescue, Survey, and Salvage Efforts:** Formalize pre-disaster relationships with private companies and public stakeholders for post-tsunami rescue and recovery efforts, clarifying roles and responsibilities and ensuring proper training for Port staff.

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

Recommended Mitigation Actions

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

- **Install tsunami signage in and around Cap Sante Marina, Curtis Wharf, Pier 1, and Pier 2.** This includes an informational kiosk about earthquake and tsunami safety for visitors and marina users.
- **Conduct a comprehensive assessment of the stability of wood pilings** supporting the Port's administration offices, evaluating susceptibility to damage from high current speeds, wave height, and debris. Based on the assessment findings, implement retrofits or replacement of pilings as necessary to ensure the overall structural integrity and resilience of the Port infrastructure against tsunami impacts.
- **Implement a plan to raise/retrofit the height of pilings throughout Cap Sante Marina** to mitigate the risk of overtopping during tsunamis, while also addressing concerns related to sea level rise, storm surge, and king tide potential. This initiative will involve

assessing the current piling heights, determining the necessary height increase, and executing retrofitting or replacement projects accordingly.

- **Conduct a comprehensive assessment of the structural integrity and resilience of docks G through Q** focusing on the through bolts that frequently break and compromise the interconnected dock system and evaluating floatation alternatives. Utilize tsunami modeling data to evaluate the capability of the docks to withstand tsunami wave momentum flux and load, particularly in comparison to the southern portion of the marina where docks have been replaced.
- **Initiate a comprehensive assessment of the cleats and anchoring infrastructure on the Docks G through Q** to identify vulnerabilities and prioritize replacement or retrofitting measures. Explore options for upgrading to concrete docks or implementing resilient cleats designed for smaller vessels to enhance stability and durability.
- **Initiate a comprehensive assessment of the central core breakwater owned and maintained by the United States Army Corps of Engineers (USACE)** to evaluate its resilience against potential tsunami wave action. Consider options such as fortification or armoring of the breakwater structure to enhance its strength and durability, thereby reducing the risk of damage and failure during extreme wave events.
- **Conduct a thorough assessment of chemical and petroleum storage facilities owned by the Port of Anacortes** to identify vulnerabilities and prioritize spill mitigation measures. This assessment will involve site inspections, hazard mapping, and risk analysis to determine the most effective strategies for reducing exposure and spill potential during tsunamis, and other natural hazards.
- **Establish Tsunami Response Asset Inventory and Mobilization Plan** to identify public and community owned assets that may be utilized to support tsunami response and recovery actions. Through establishing MOUs and pre-disaster contracts, this may be a feasible option to consider.

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