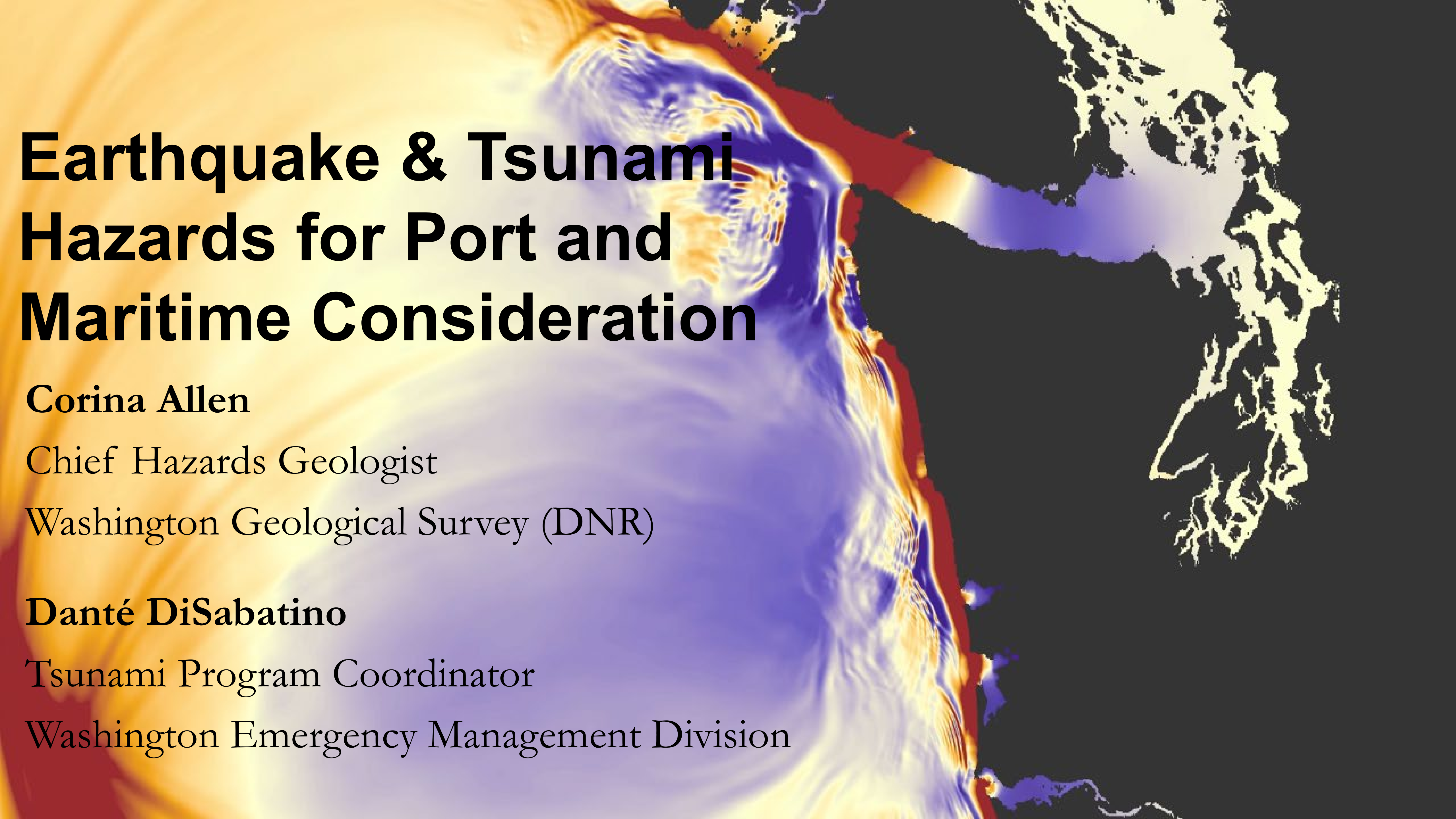


Earthquake & Tsunami Hazards for Port and Maritime Consideration

Corina Allen

Chief Hazards Geologist

Washington Geological Survey (DNR)

Danté DiSabatino

Tsunami Program Coordinator

Washington Emergency Management Division

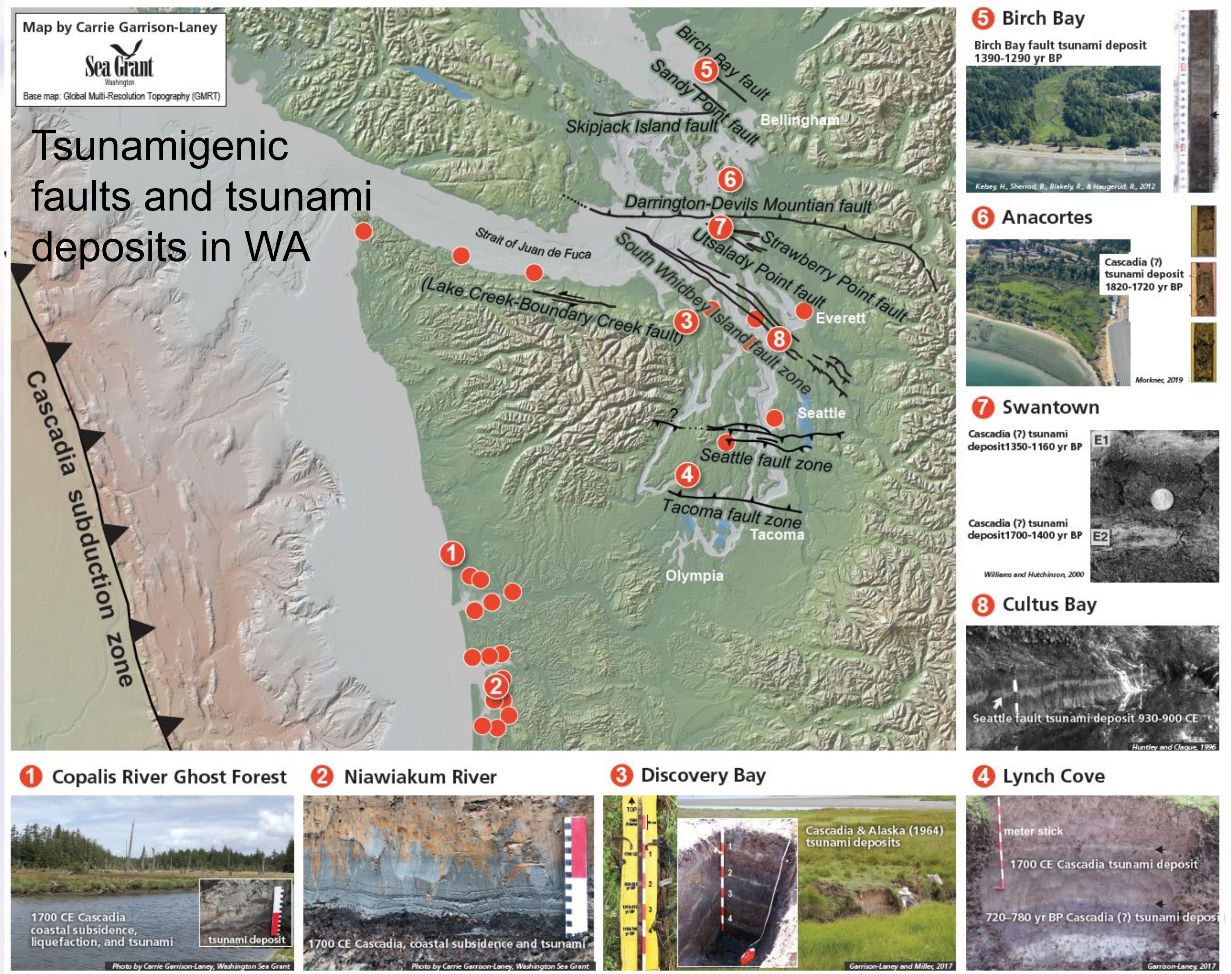
Earthquake Hazards in Washington

How likely are major earthquakes?

Cascadia Subduction Zone:
Giant (M 8.0-9.0) earthquake every 300-600 years
~15-25% probability in the next 50 years

Crustal Faults:
~Magnitude 6-7.5+
~ 15% probability in 50 years

Deep Slab Earthquakes (2001 Nisqually type):
Magnitude 7-ish
Most common type
~85% chance in 50 years



Earthquakes are inevitable, but when, where, and how are uncertain

Types of Tsunamigenic Earthquake Sources

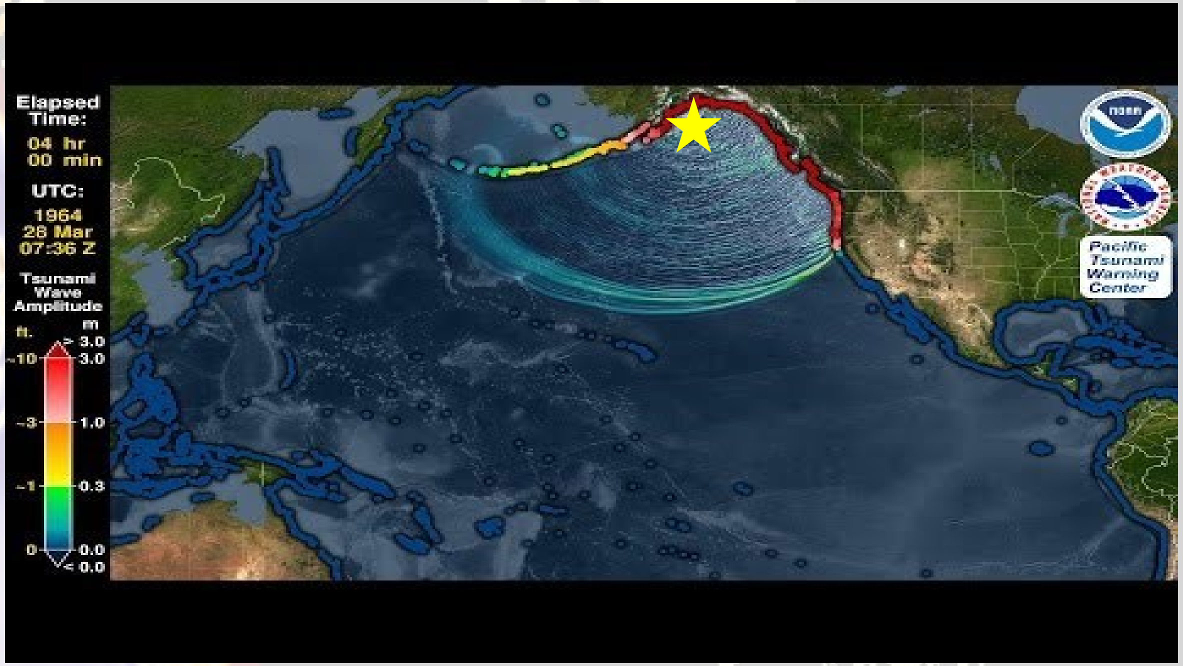
For earthquakes there are several types to consider.

Distant source (Alaska) – These arrive from far off lands providing some advanced warning, are most often to occur, and generally less hazardous*
Warning must be distributed

Local source (Cascadia) – This will be a regional event impacting all the PNW, little to no warning, limited evacuation time, and most destructive regionally
Shaking is warning

Local source crustal faults (ex: Seattle fault) – These will be locally impactful events, little to no warning, limited evacuation time, locally destructive.
Shaking is warning

*All tsunamis may pose a threat to maritime interests even if not significant for inundation/evacuation purposes



Earthquake Shaking

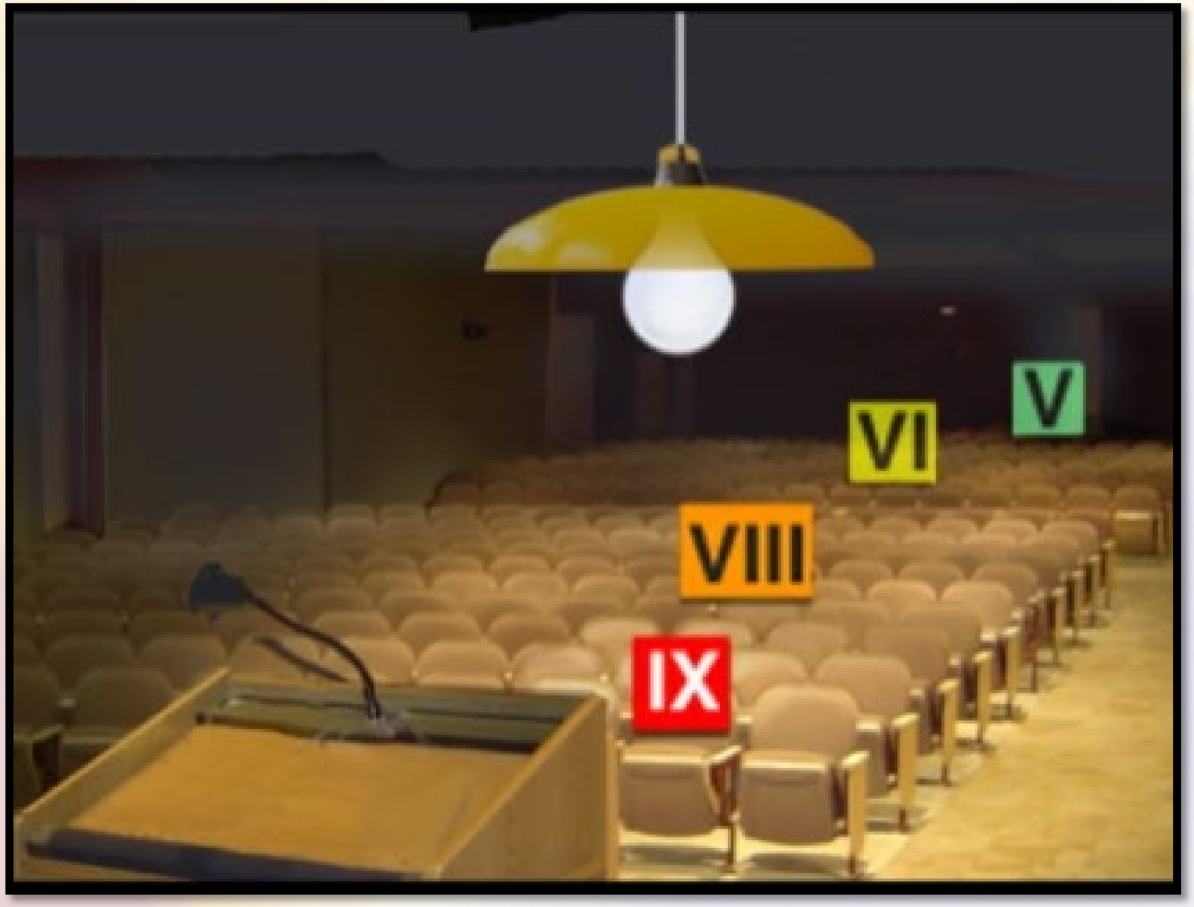
The shaking you will experience depends on:

(1) Earthquake MAGNITUDE

(2) LOCATION relative to earthquake

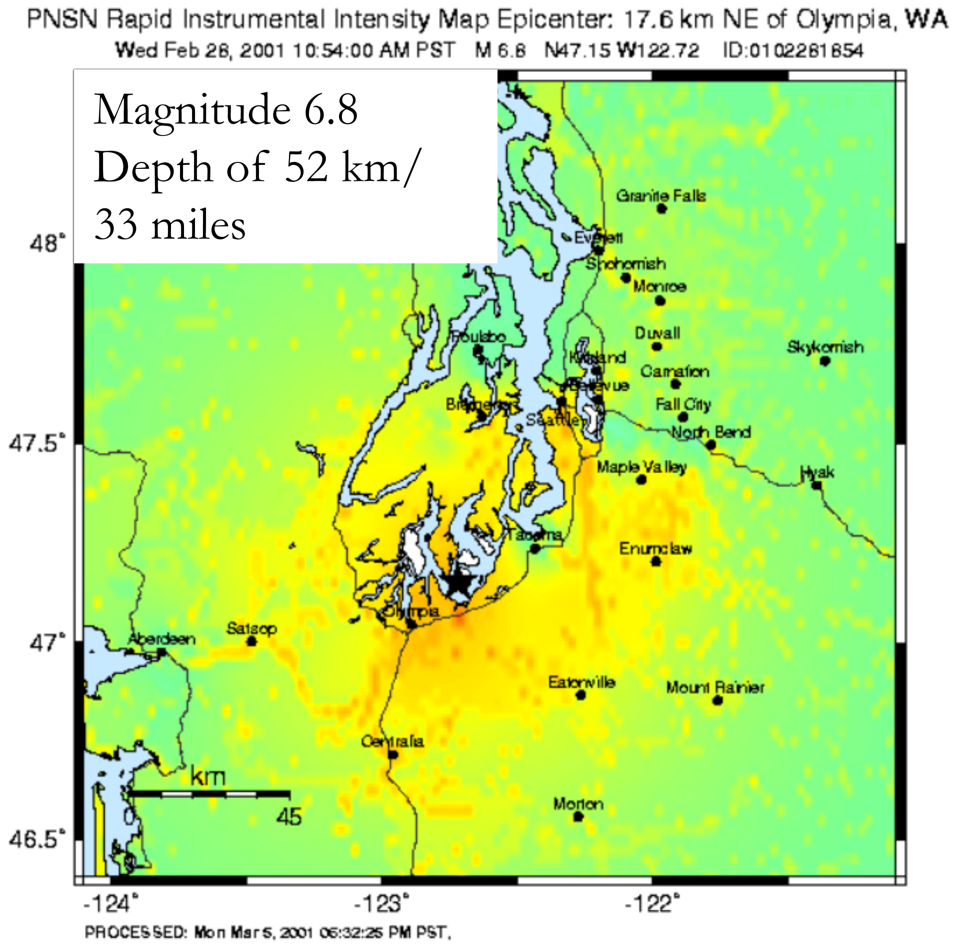
(3) Local soil and rock conditions

Mercalli Scale:
A measure of intensity

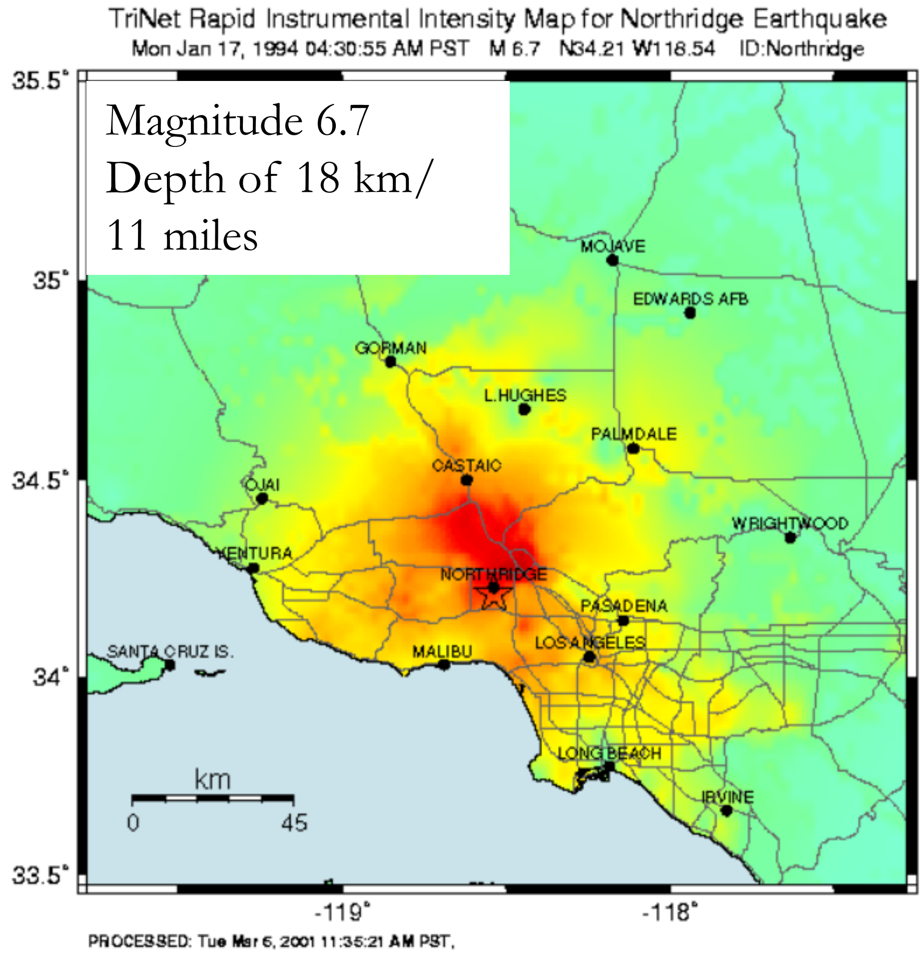


Intensity	Shaking	Description
I	Not felt	Not felt except by a very few under especially favorable conditions.
II	Weak	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do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

2001 Nisqually vs. 1994 Northridge



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

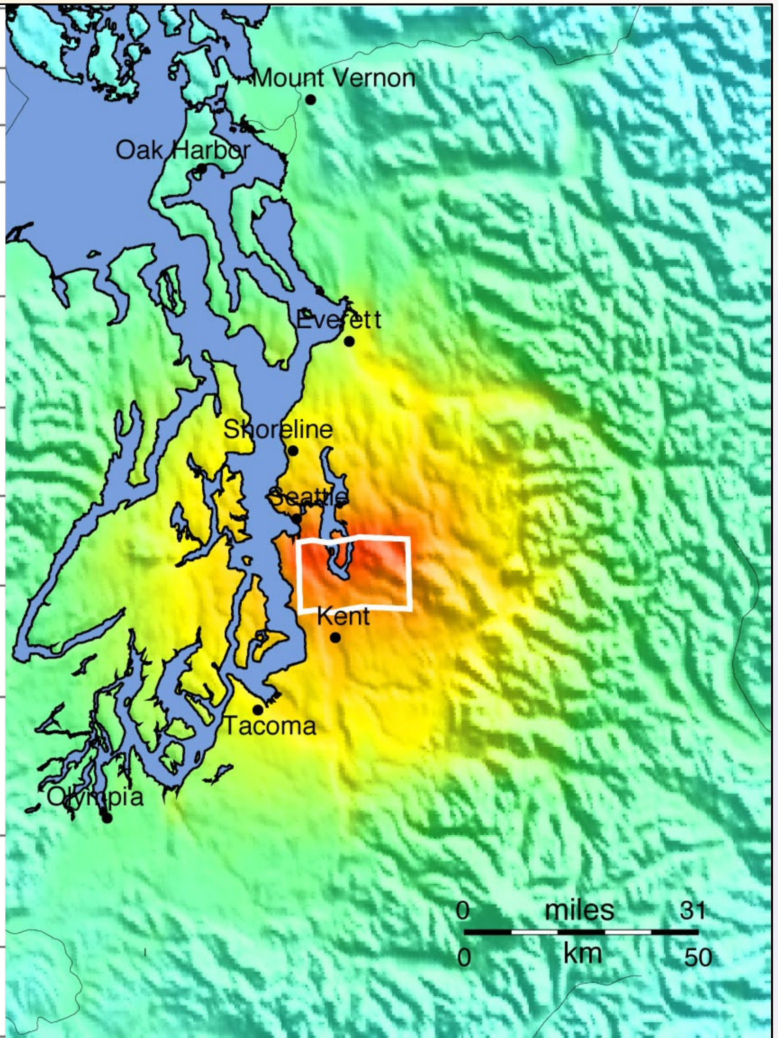


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

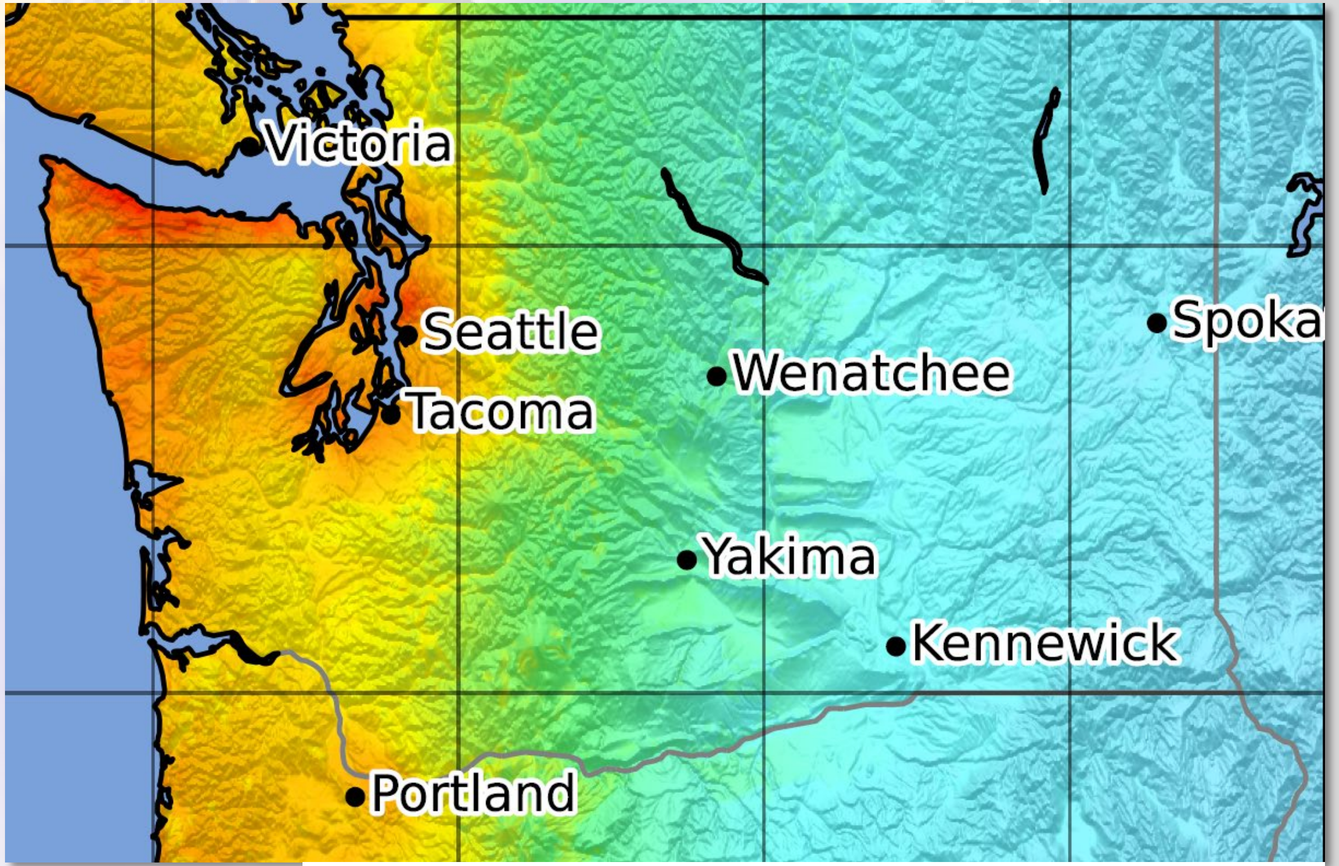
USGS ShakeMaps

Seattle fault zone

Intensity	Shaking
I	Not felt
II	Weak
III	Weak
IV	Light
V	Moderate
VI	Strong
VII	Very strong
VIII	Severe
IX	Violent
X+	Extreme



Cascadia subduction zone



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0464	0.297	2.76	6.2	11.5	21.5	40.1	74.7	>139
PGV(cm/s)	<0.0215	0.135	1.41	4.65	9.64	20	41.4	85.8	>178
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Worden et al. (2012)

Impacts from Earthquakes

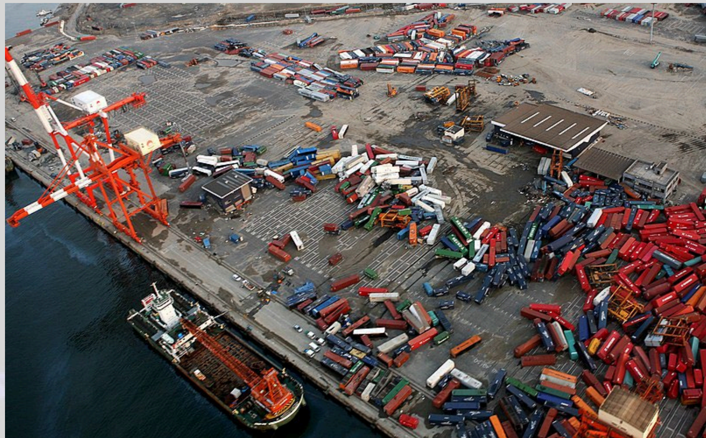
- **Ground Shaking:** Damage to infrastructure (ports, docks, piping, bridges roads etc.), chemical/biological spills, fires

- **Liquefaction:** Most all ports are built on mud, sand, and fill which is highly susceptible to liquefaction.

- **Soil Settlement:** (unaffiliated with liquefaction):Loss of pore water pressure in soils, compaction.

Ground Settlement at Port of Sendi
Photo Credit: ASCE

Refinery Fire in Chiba Prefecture
Photo Credit: European Pressphoto Agency



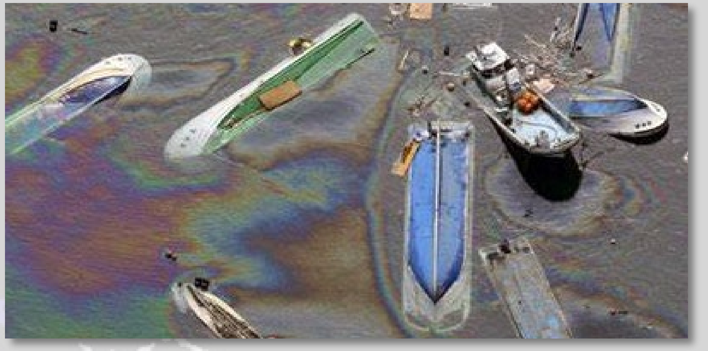
Tsunami shifted containers
Photo Credit: U.S. Marine Corps Photo by Cpl. Megan Angel/Released

Impacts from Tsunamis (maritime specific):

- **Damage bridges, overpasses, roadways**, and other vulnerable transportation infrastructure
- **Damage port/marina infrastructure and goods**, impacting shipping and supply chains
- **Alter water channels**, requiring sounding and potentially dredging before vessels can navigate them again
- **Debris**
- **Scour and erosion**
- **Contaminated water/sediment and other environmental hazards**

<u>Recent example 2011 Japan:</u>

- Japanese officials estimated that **2,126 roads and 56 bridges were damaged** during the 2011 earthquake and tsunami
- **28,000+ ships were also destroyed**, along with **319 ports**
- **Economic loss of $3.9 Billion/day**

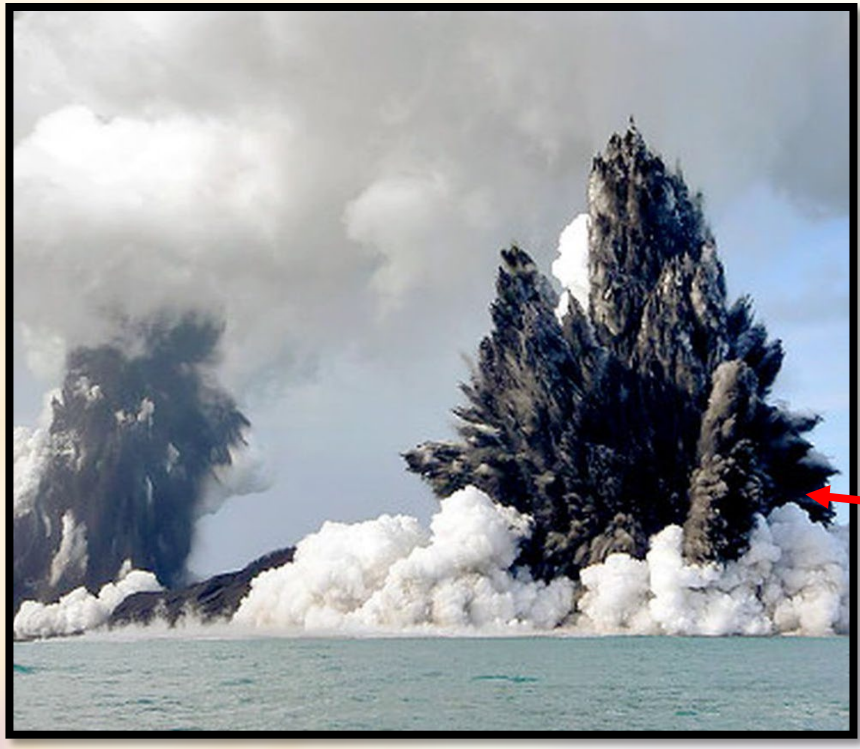


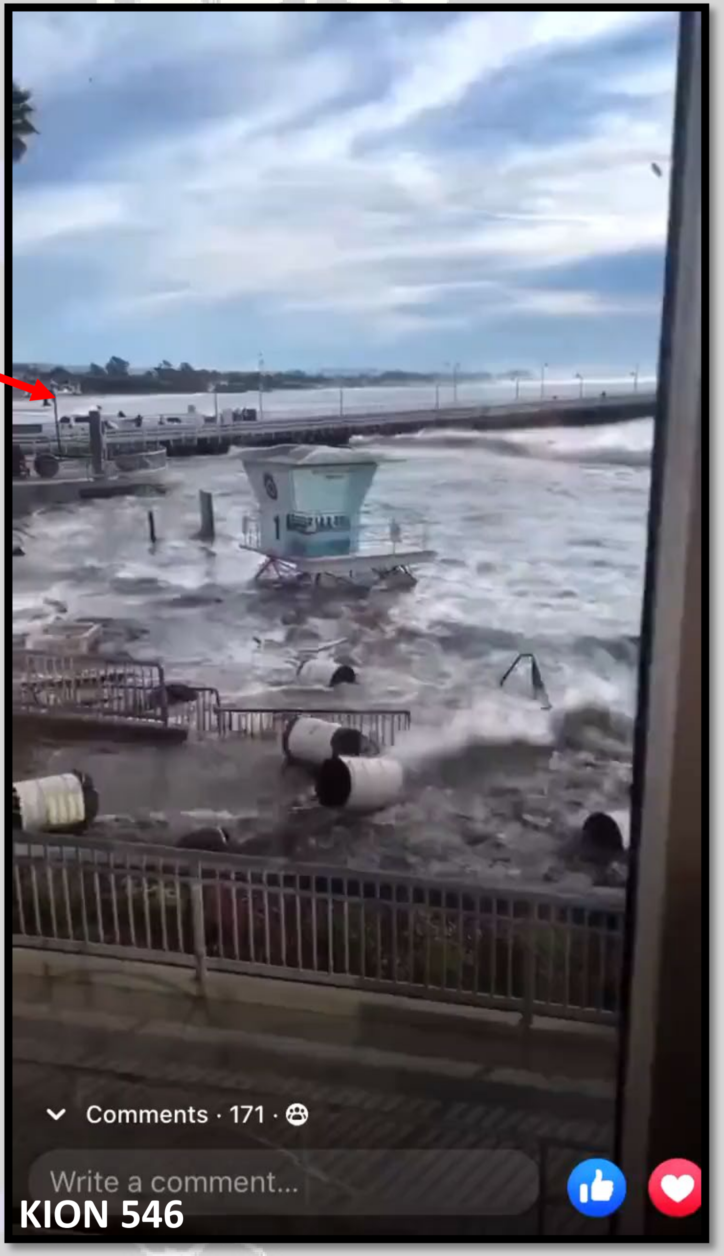
Distant Source Tsunami Impact: Economic/Strategic Losses

California, 2011

- $100M in damage
- 24+ harbors hit with the tsunami
- Some closed for up to a year

Distant Source Tsunami Impact: 2022 Hunga Tonga



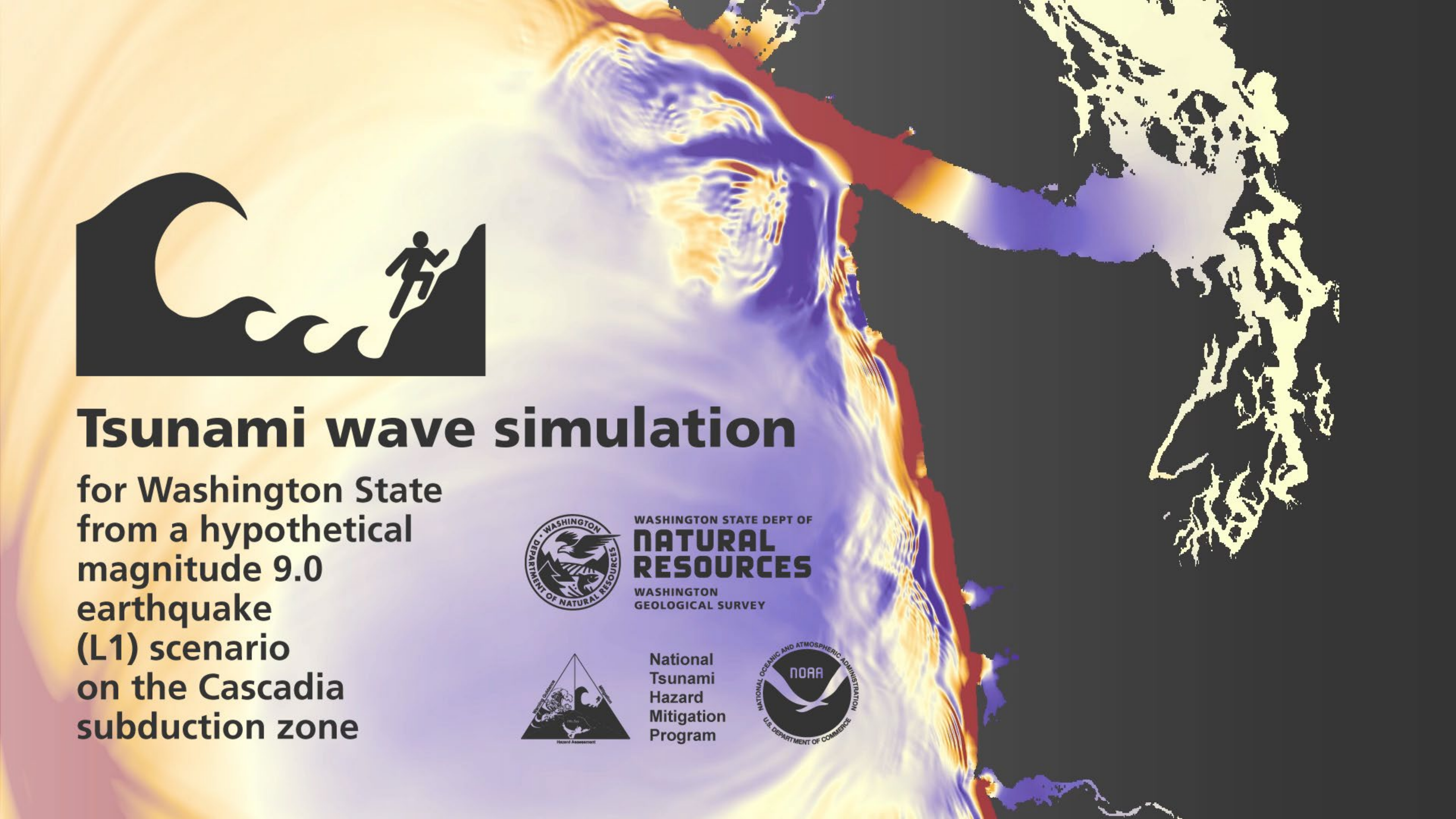


- **$6.5M in damage to Santa Cruz Harbor's** dredge, dredge pipe, docks/piles, & inundation flooding of harbor infrastructure
- Heavy currents tore away docks & twisted dredge steel piping
- **$1-2M in damages in Ventura Harbor**, primarily to docks and piles and a capsized harbor patrol boat

California information provided by Rick Wilson, California Geological Survey. For more CA state tsunami information, visit tsunami.ca.gov

Tsunami Hazards for Maritime Infrastructure and Vessels

- **Strong and unpredictable currents** in narrows of harbors
- **Water-level fluctuations** can overtop piles, ground boats, push boats over docks
- **Tsunami bores and amplified waves** can swamp boats and damage docks
- **Eddies/whirlpools** can cause boats to lose control

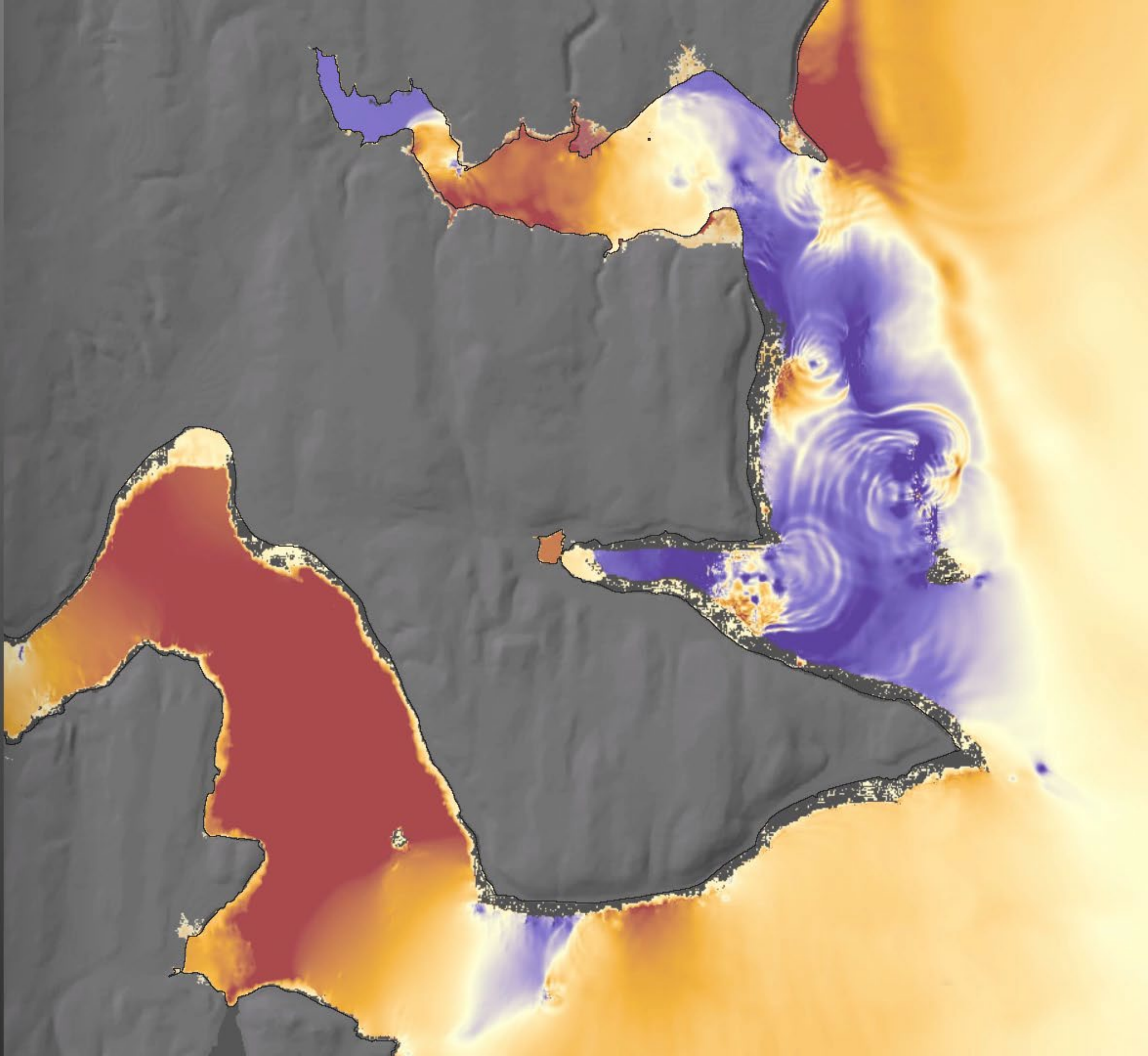

Tsunami wave simulation
for Washington State from a hypothetical magnitude 9.0 earthquake (L1) scenario on the Cascadia subduction zone
WASHINGTON STATE DEPT OF NATURAL RESOURCES
WASHINGTON GEOLOGICAL SURVEY
National Tsunami Hazard Mitigation Program
NOAA

Tsunami wave simulation

for southern Bainbridge Island and portions of the Kitsap Peninsula, Washington, from a large Seattle Fault earthquake scenario

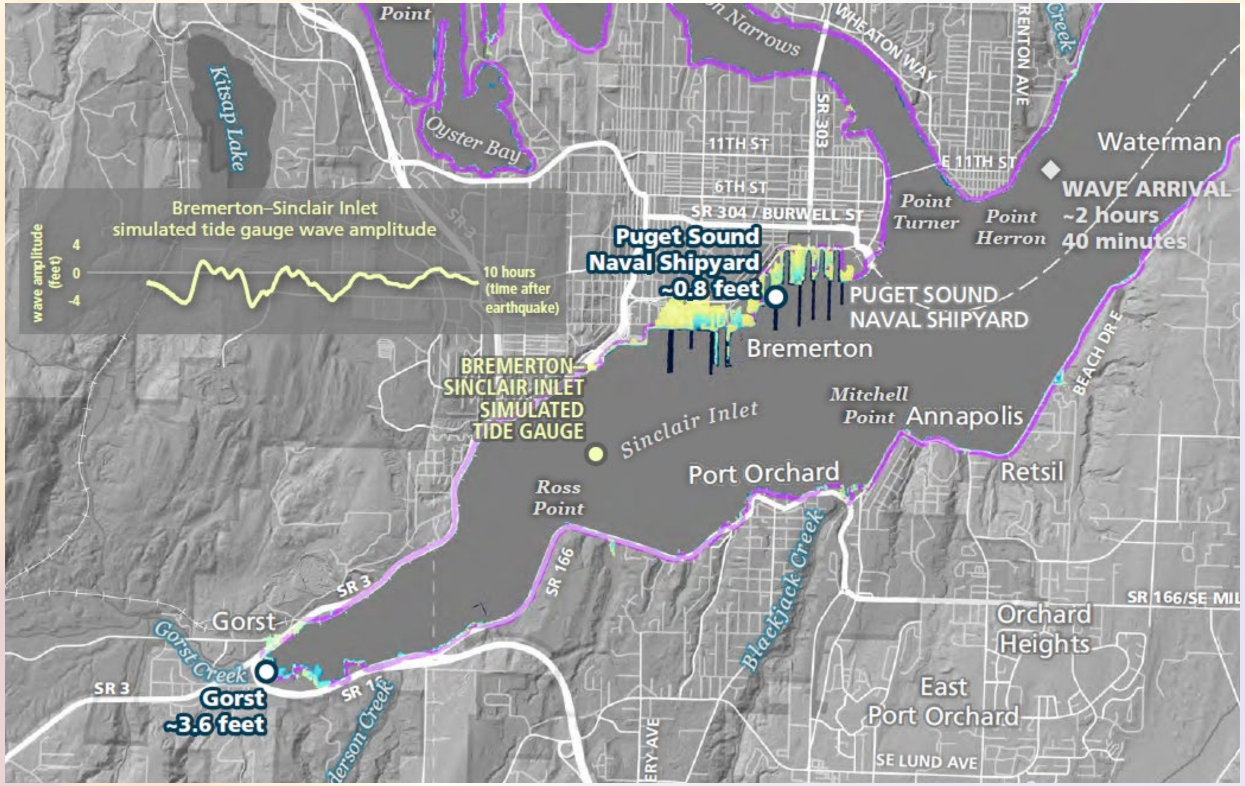
WASHINGTON STATE DEPT OF NATURAL RESOURCES
WASHINGTON GEOLOGICAL SURVEY

National Tsunami Hazard Mitigation Program

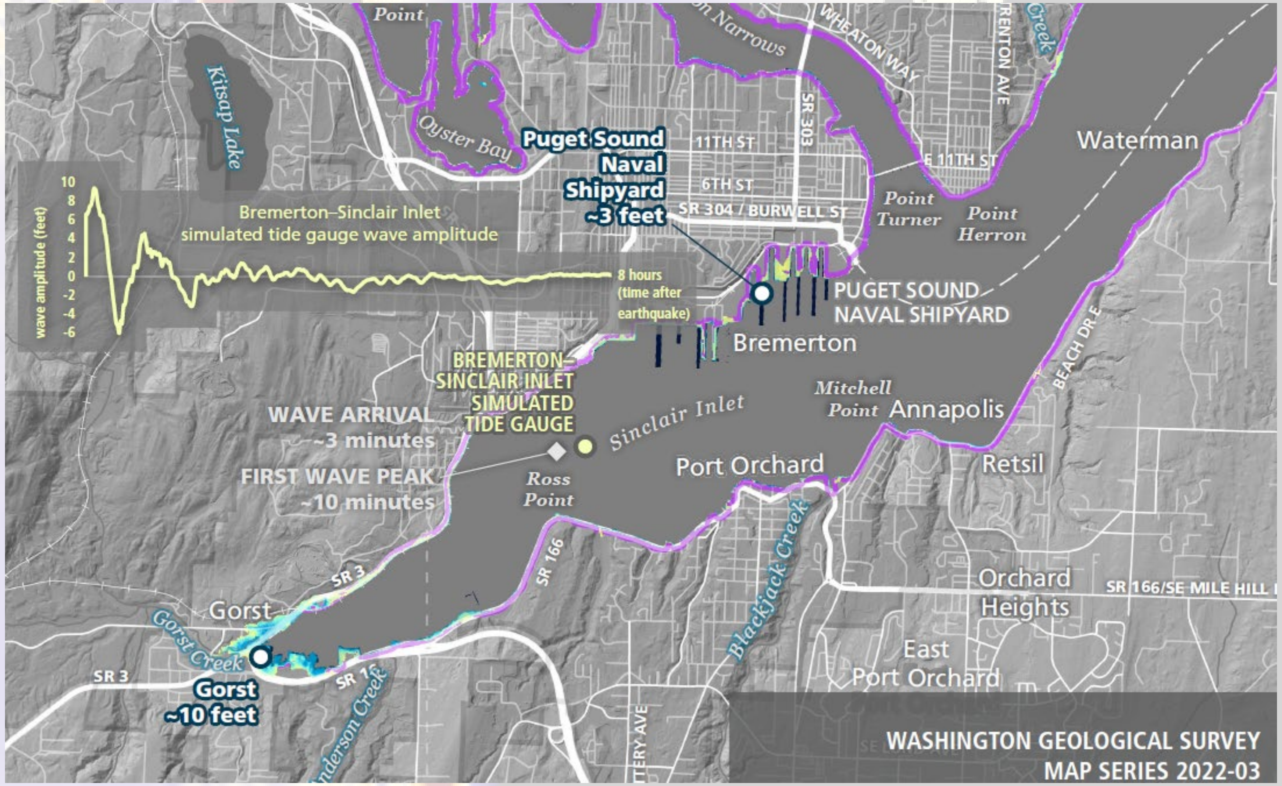


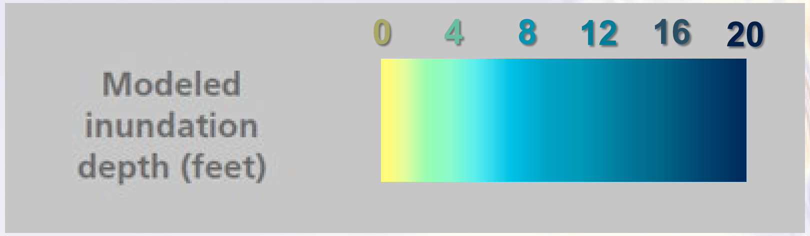
Maximum inundation: Bremerton

Cascadia



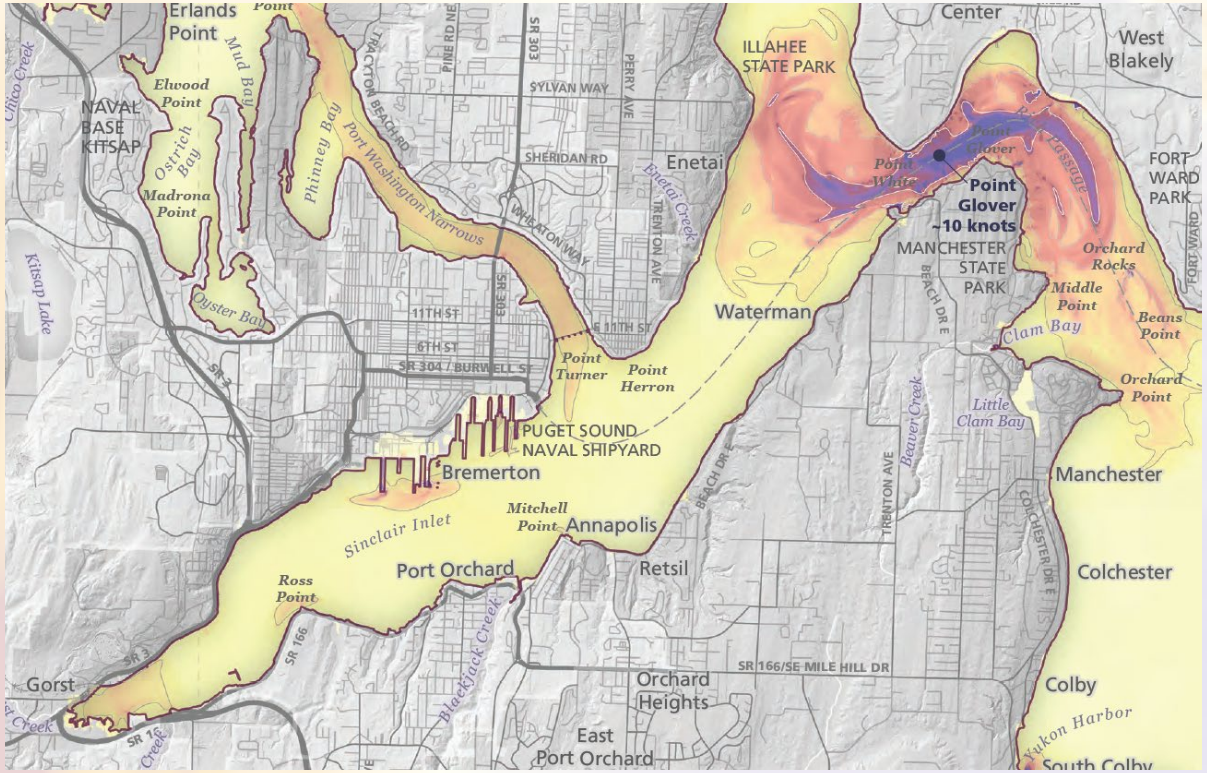
Seattle fault



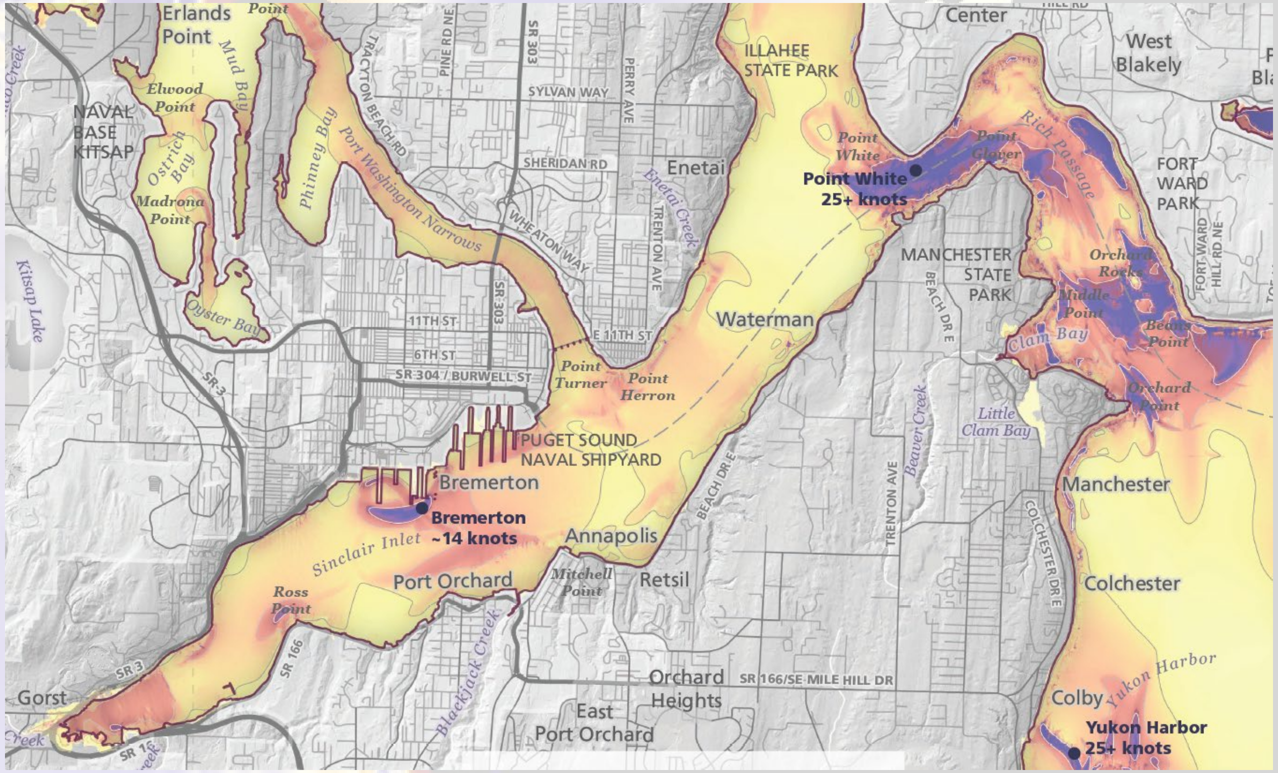


Maximum current speed: Bremerton

Cascadia



Seattle fault



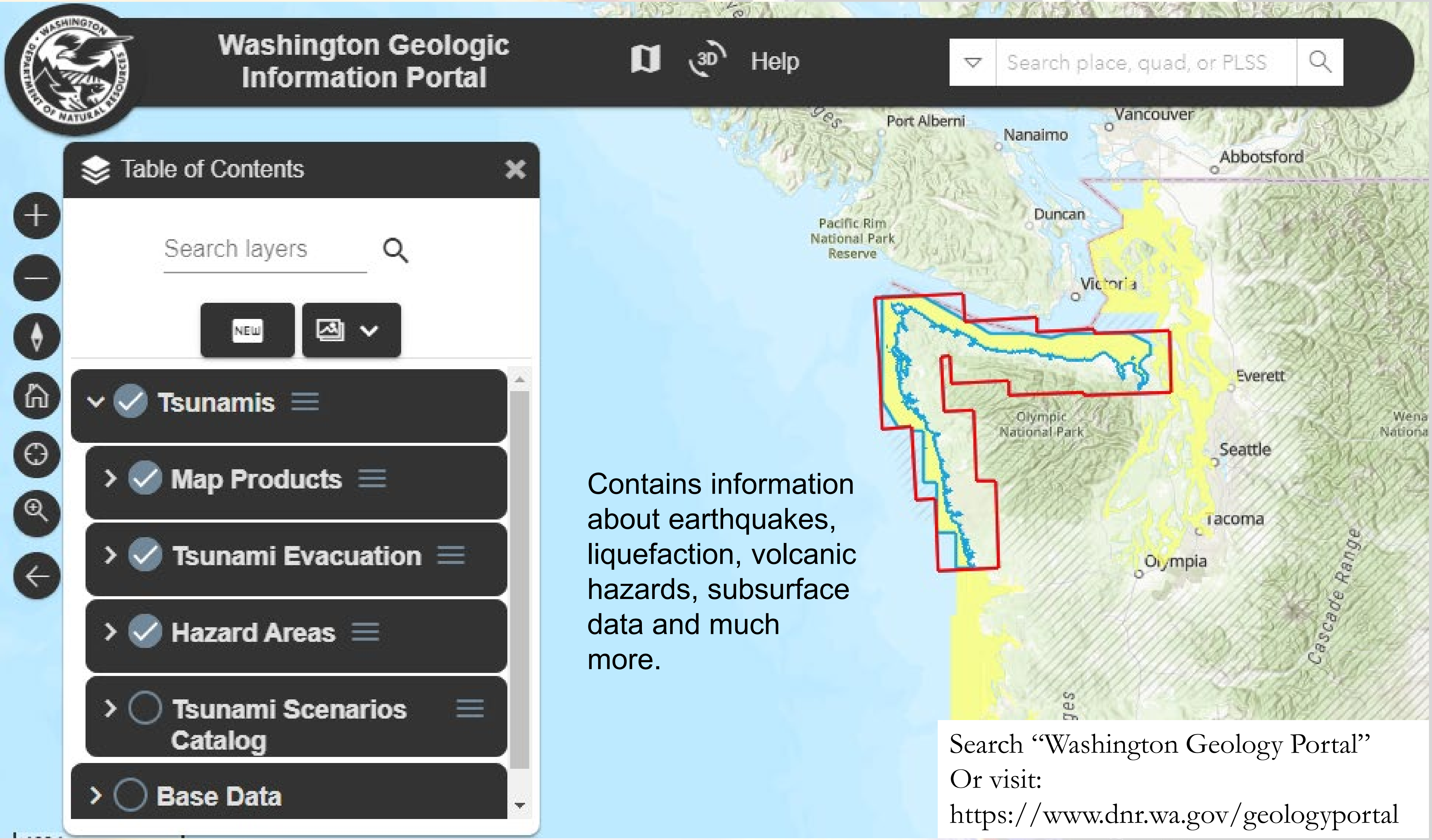
Modeled maximum current speed (knots)

0-3	3-6	6-9	>9

WGS tsunami webpage

https://www.dnr.wa.gov/programs-and-services/geology/geologic-hazards/Tsunamis

- Tsunami science
- Tsunami history
- Tsunami resources (hazard maps, evacuation maps, simulations and more)
- Interpretive graphics and data



Contains information about earthquakes, liquefaction, volcanic hazards, subsurface data and much more.

Search "Washington Geology Portal"
Or visit:
https://www.dnr.wa.gov/geologyportal

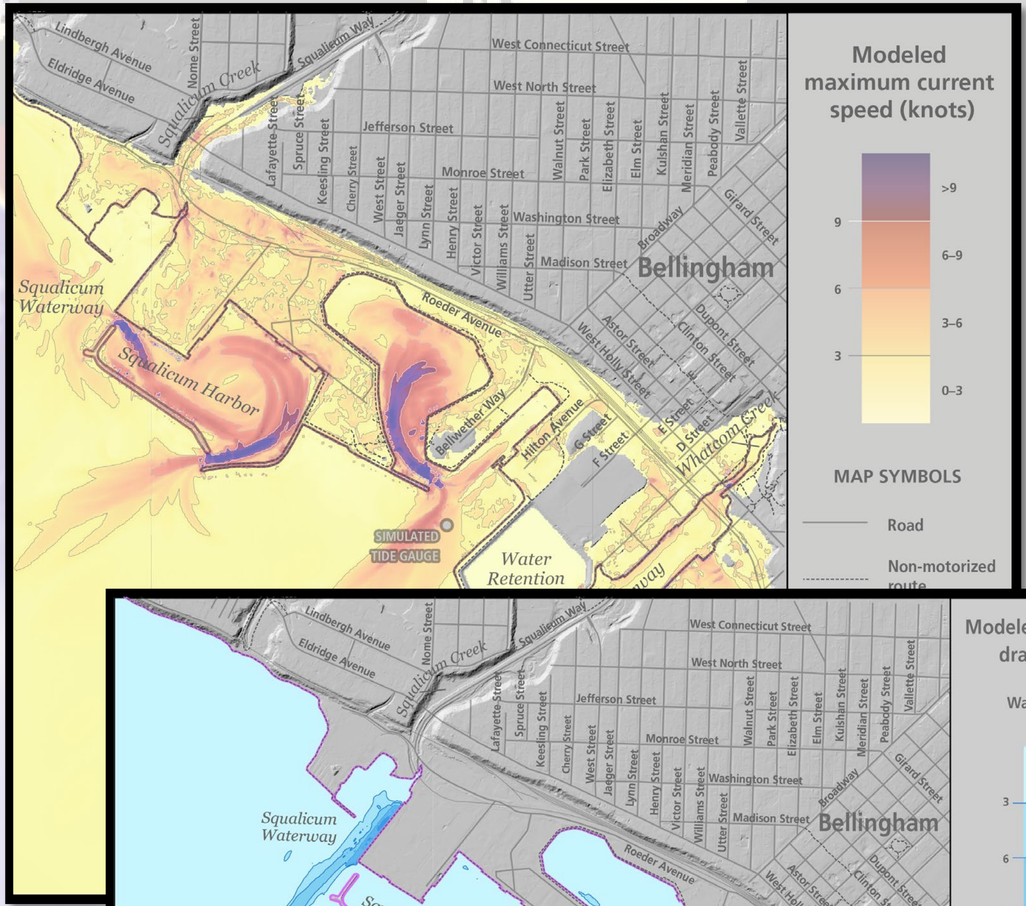
Tsunami Maritime Response and Mitigation Strategies

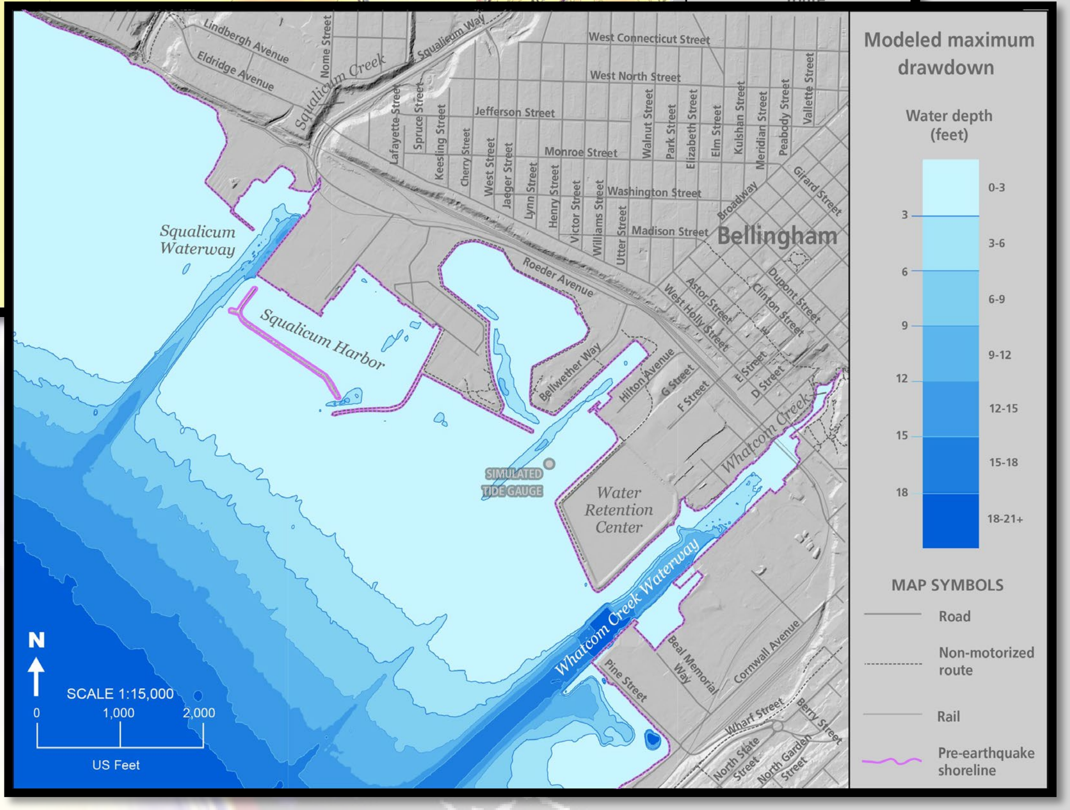
Focuses on the tsunami threat to the maritime community in a specific port, harbor, or marina

Include sections on:

- Intro to tsunami maritime risk and hazards
- Site-specific maps of waterways showing inundation, dangerous currents, and modeled minimum water depths (drawdown)
- Protective action guidance for boaters
- Outlines roles/responsibilities and gaps in tsunami maritime response
- Identifies tsunami mitigation opportunities and gaps

First WA TMRMS for the **Port of Bellingham; Second strategy for Westport Marina** find it at [**mil.wa.gov/tsunami**](mil.wa.gov/tsunami)

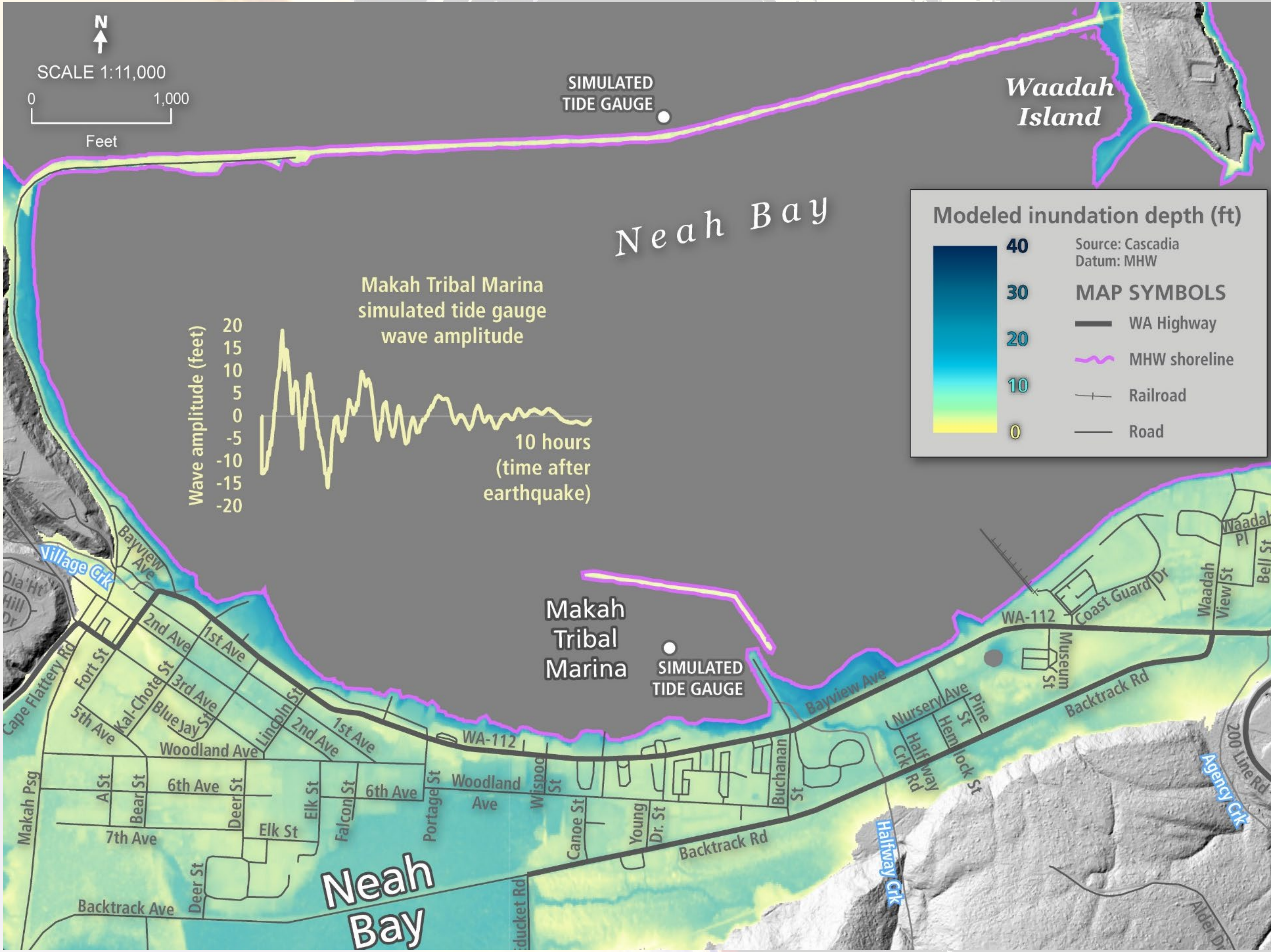




Inundation Maps

Example:

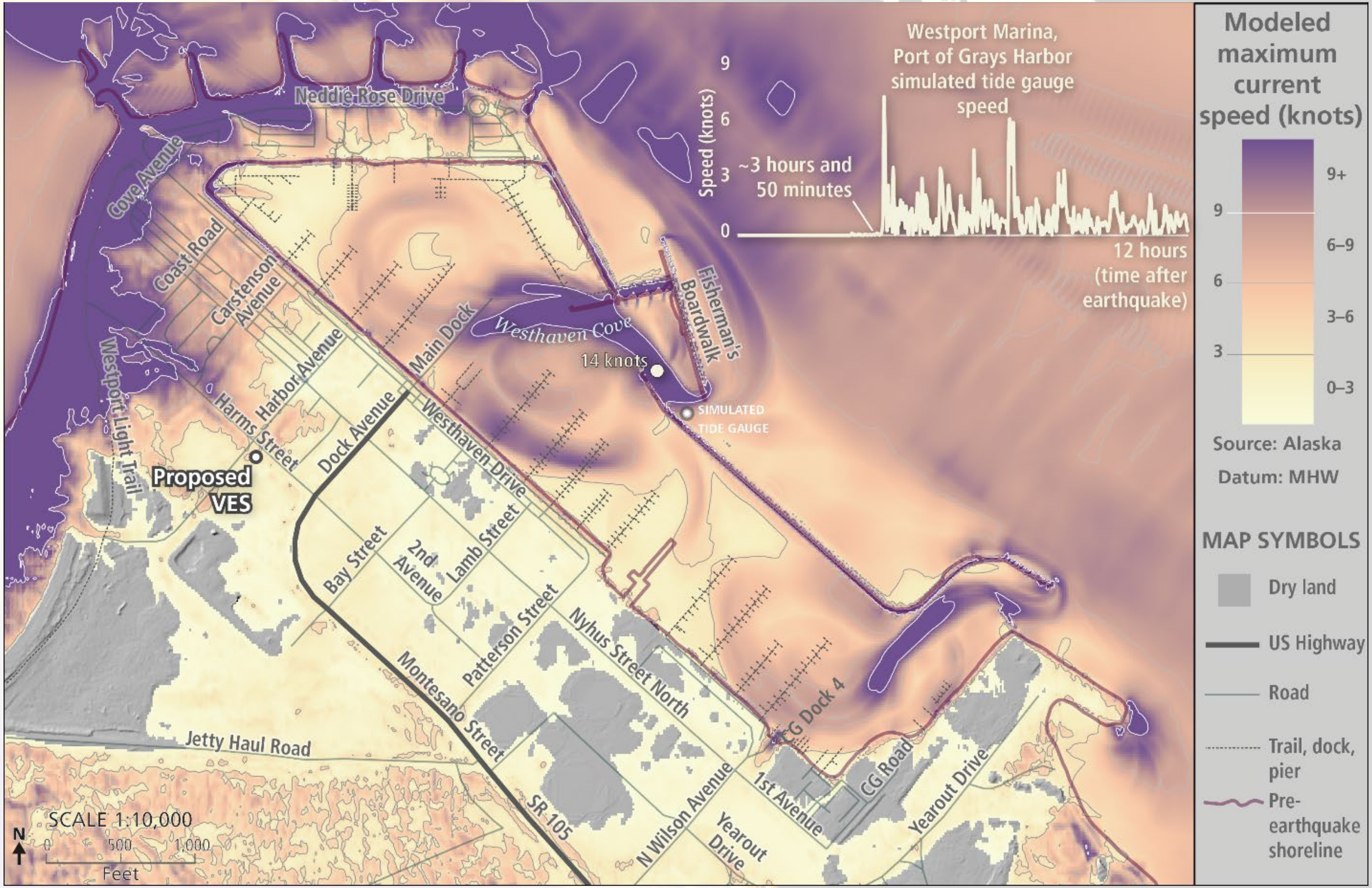
- Cascadia Subduction Zone (CSZ)
- Port of Neah Bay
- Highest resolution model for the port areas to date



Max Current Speed Maps

Example:

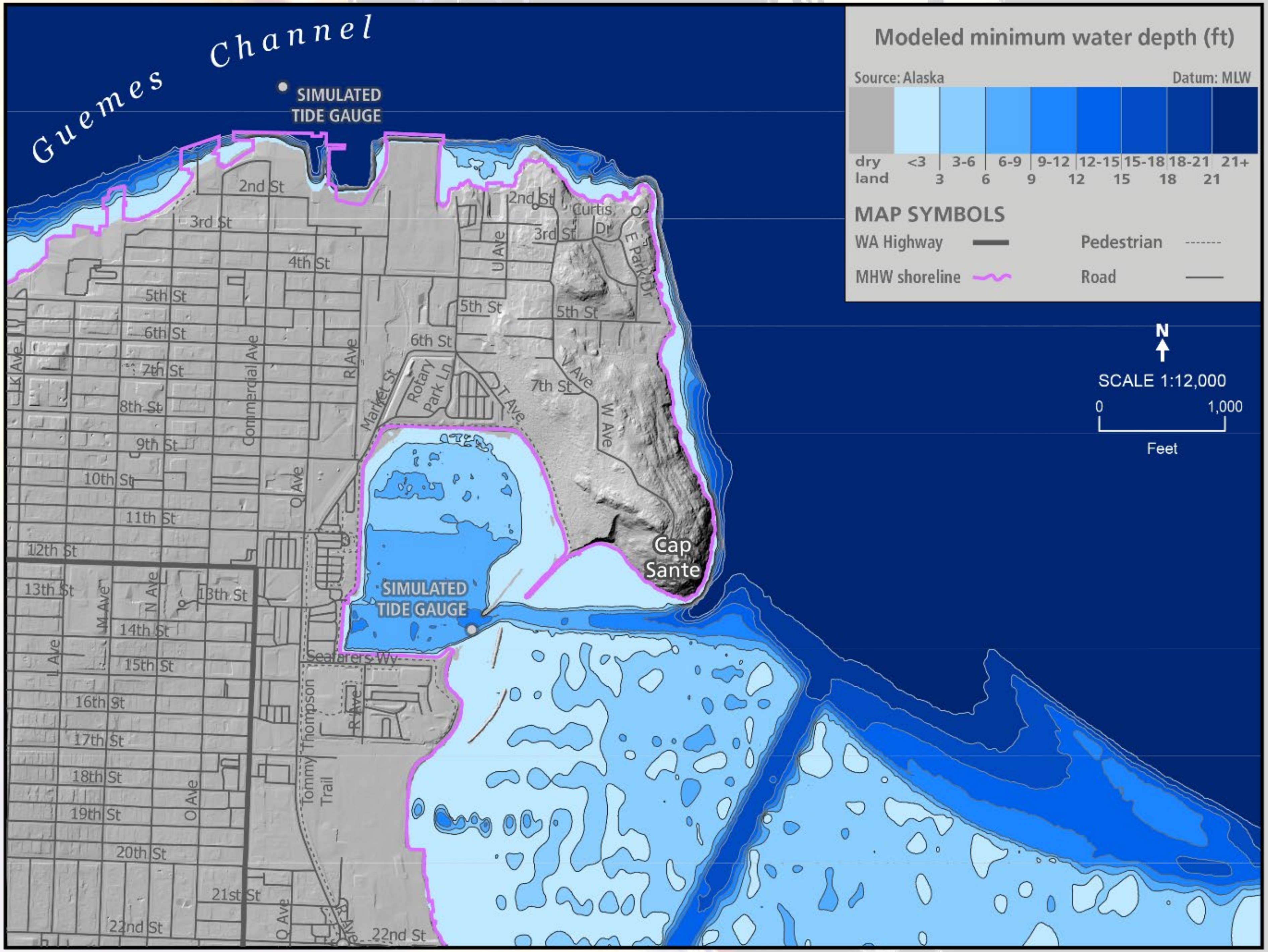
- Alaskan Aleutian Subduction Zone (AASZ)
- Westport Marina, Port of Grays Harbor
- DEM corrections improve inflow – outflow of narrow harbor entrances



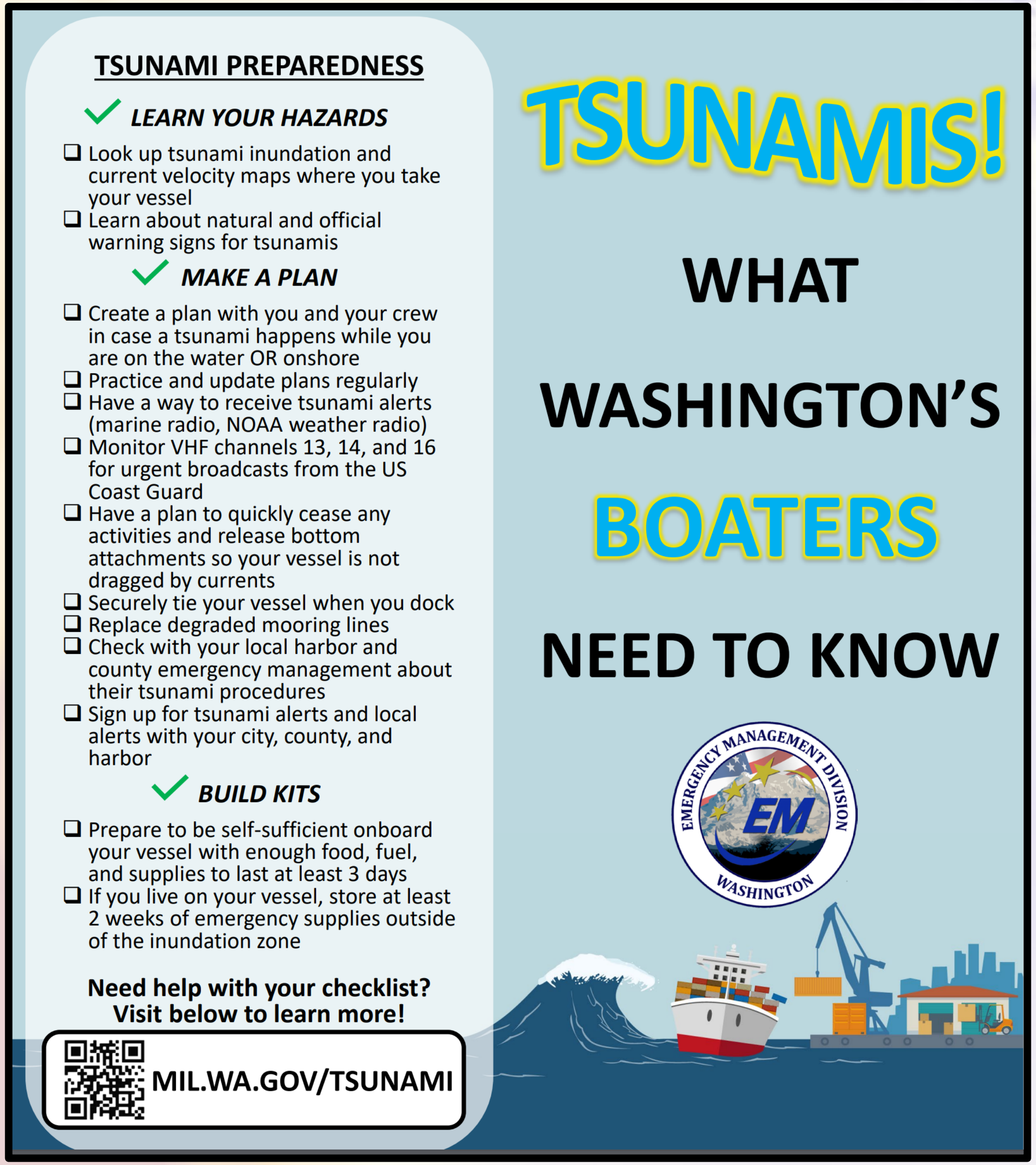
Min Water Depth Maps

Example:

- Alaskan Aleutian Subduction Zone (AASZ)
- Port of Anacortes
- Product not available elsewhere



Response Factors for Boaters To Consider



TSUNAMI PREPAREDNESS

✓ *LEARN YOUR HAZARDS*

- ❑ Look up tsunami inundation and current velocity maps where you take your vessel
- ❑ Learn about natural and official warning signs for tsunamis

✓ *MAKE A PLAN*

- ❑ Create a plan with you and your crew in case a tsunami happens while you are on the water OR onshore
- ❑ Practice and update plans regularly
- ❑ Have a way to receive tsunami alerts (marine radio, NOAA weather radio)
- ❑ Monitor VHF channels 13, 14, and 16 for urgent broadcasts from the US Coast Guard
- ❑ Have a plan to quickly cease any activities and release bottom attachments so your vessel is not dragged by currents
- ❑ Securely tie your vessel when you dock
- ❑ Replace degraded mooring lines
- ❑ Check with your local harbor and county emergency management about their tsunami procedures
- ❑ Sign up for tsunami alerts and local alerts with your city, county, and harbor

✓ *BUILD KITS*

- ❑ Prepare to be self-sufficient onboard your vessel with enough food, fuel, and supplies to last at least 3 days
- ❑ If you live on your vessel, store at least 2 weeks of emergency supplies outside of the inundation zone

Need help with your checklist? Visit below to learn more!

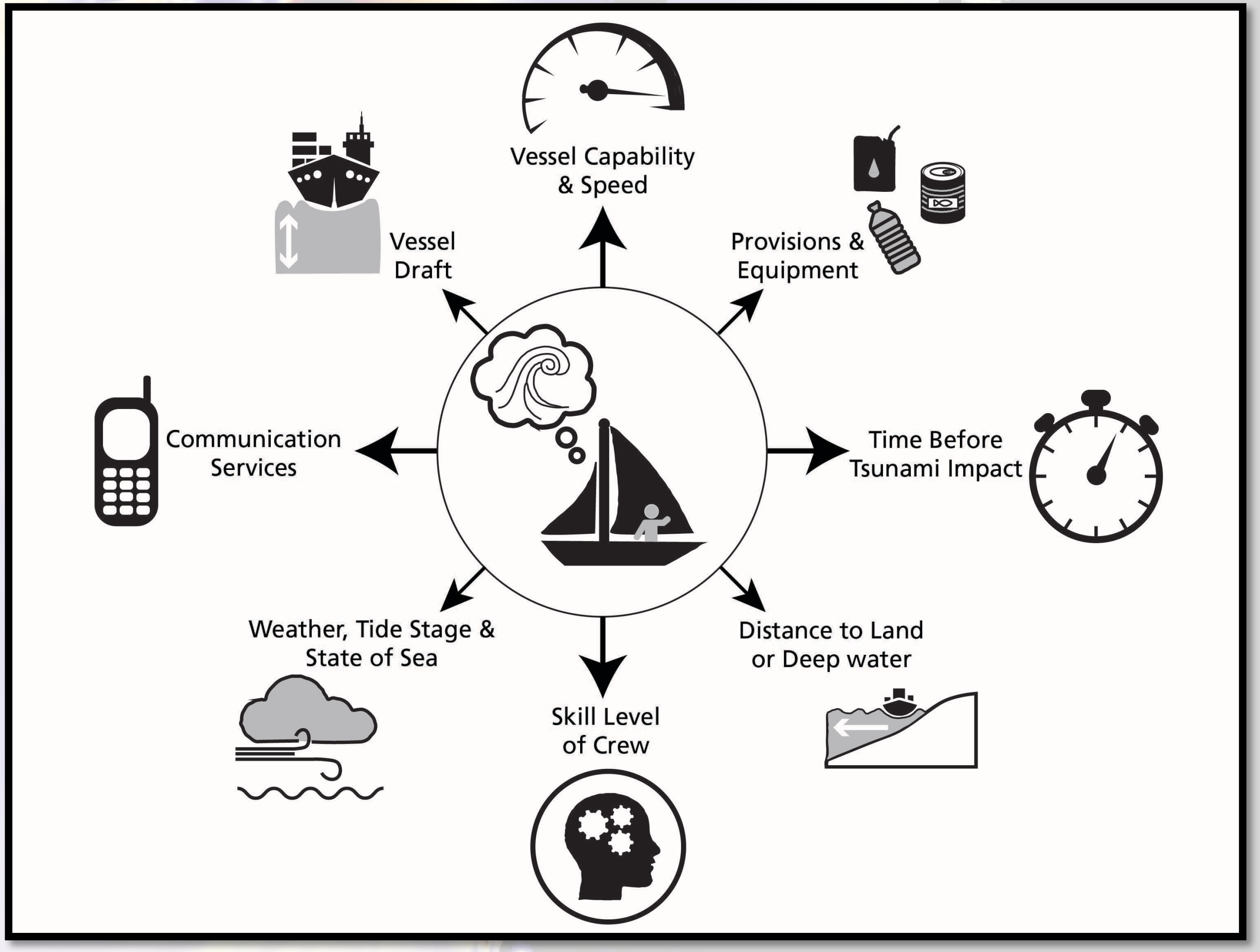
MIL.WA.GOV/TSUNAMI

TSUNAMIS!

WHAT WASHINGTON'S BOATERS NEED TO KNOW

EMERGENCY MANAGEMENT DIVISION EM WASHINGTON

What will boaters do when they receive an alert?



Tsunami Response Actions for Ports to Consider

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

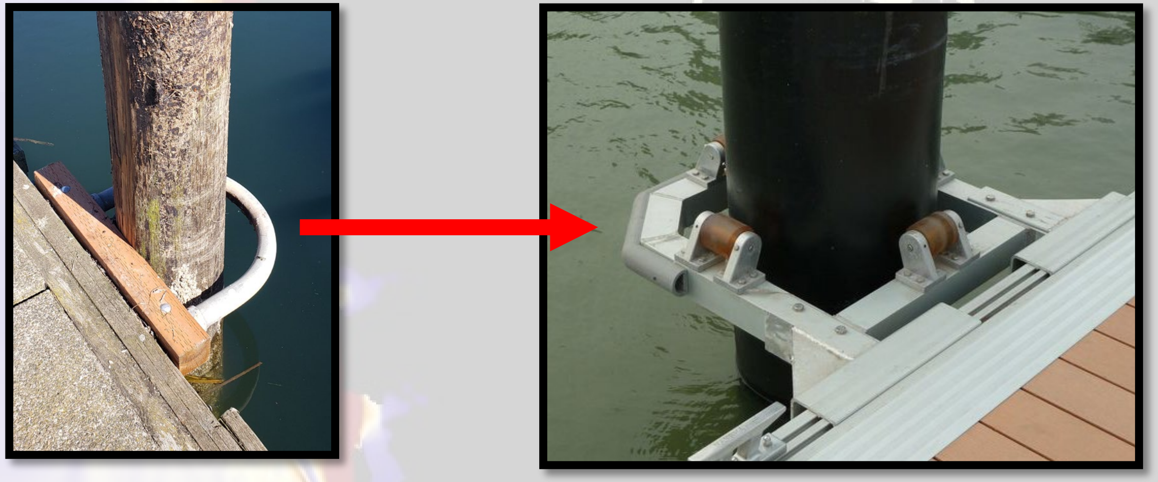
- **Is this applicable and feasible for the Port ?**
- **To initiate, who needs to be at the table or who gives approval?**
- **Will this require collaboration in the moment? Is this something the Port can do on its own?**
- **How long will it take to initiate?**
- **Are there other plans** (i.e., EM Plans, Capital Improvement Plans, Tsunami Response plans) **that should be referenced for this? If so, what are the names of the plans?**

Tsunami Mitigation Actions for Ports to Consider

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

Strengthen cleats and single point moorings

Improve movement along dock/pile connections



Mitigation Actions→ HM Plans→ Funding $$$

Thanks for Joining Us!

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Washington Geological Survey

Danté DiSabatino, ***Tsunami Program Coordinator***
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Washington State Emergency Management Division

dnr.wa.gov/tsunami

mil.wa.gov/tsunami

Supplemental Material for Q&A

Tsunami Response Actions

1. Shut Down Marina Infrastructure Before Tsunami Arrives
2. Evacuate Public/Vehicles from Waterfront Areas
3. Informing and Coordinating with Key First Responders During a Tsunami
4. Identify Boat Owners/Individuals Who Live Aboard Vessels and Establish Notification Processes
5. Pre-Identify Personnel to Assist in Rescue, Survey and Salvage Efforts
6. Move Vessels Out of the Marina
7. Restrict Traffic Entering the Marina by Land and Aid in Traffic Evacuation
8. Reposition Ships Within the Marina
9. Pre-Stage Emergency Equipment Outside Affected Area
10. Restrict Boats from Moving and Prevent Ships from Entering the Port During a Tsunami
11. Remove Buoyant Assets Out of and Away from the Water

Consider the following when we discuss each response action:

- Is this applicable and feasible for the Port and Guemes Channel area? (Yes, Needs Review, No)
- To initiate, who needs to be at the table or who gives approval? (Write down names, agency/position, and email if possible)
- Will this require collaboration in the moment? Is this something the Port can do on its own?
- How long will it take to initiate?
- How would this be communicated to boaters, staff, and other Port users? How do these plans intersect with the surrounding area?
- Are there other plans (i.e., EM Plans, Capital Improvement Plans, Tsunami Response plans) that should be referenced for this? If so, what are the names of the plans?
- Any other considerations, thoughts, and/or adaptations?

Maritime Guidance

Existing National Guidance

Specific regional guidance for minimum offshore safe depths for maritime vessel evacuation prior to the arrival of tsunami.			
State/Territory	**Distant Source (ships in harbor)**	**Local Source (ships at sea)**	**Notes on this Update**
California	30 fathoms	100 fathoms	Evaluated; evaluating potential safe areas within large bays and ports
Oregon	30 fathoms	100 fathoms	Evaluated; also evaluating Columbia River
Alaska	30 fathoms	100 fathoms	Evaluated; ships should be at least 1/2 mile from shore for all scenarios
Washington	30 fathoms (180 feet)	100 fathoms (600 feet)	Evaluated; evaluating special conditions exist inside Puget Sound

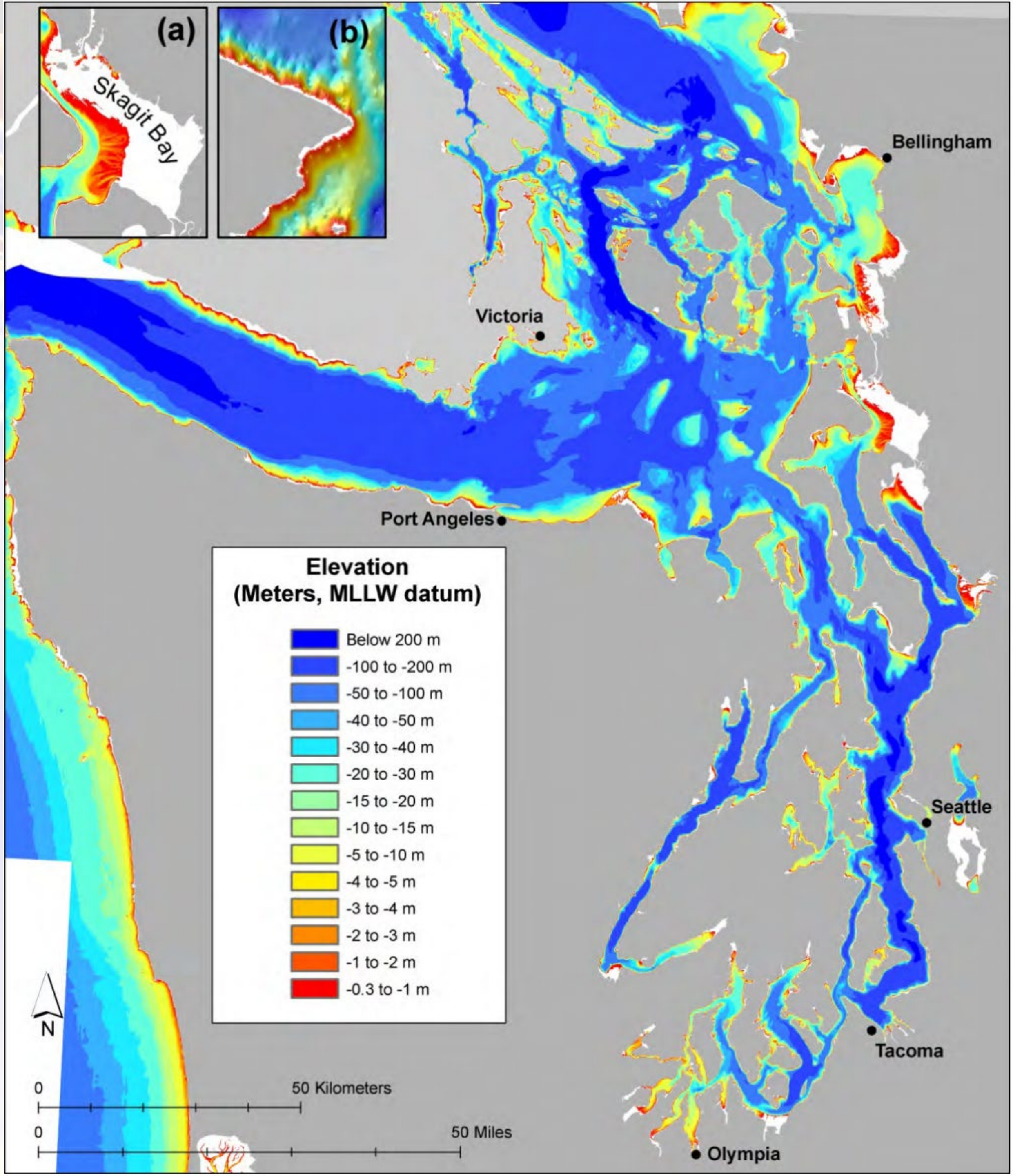
Bathymetry of Washington

Distant Source (ships in harbor)

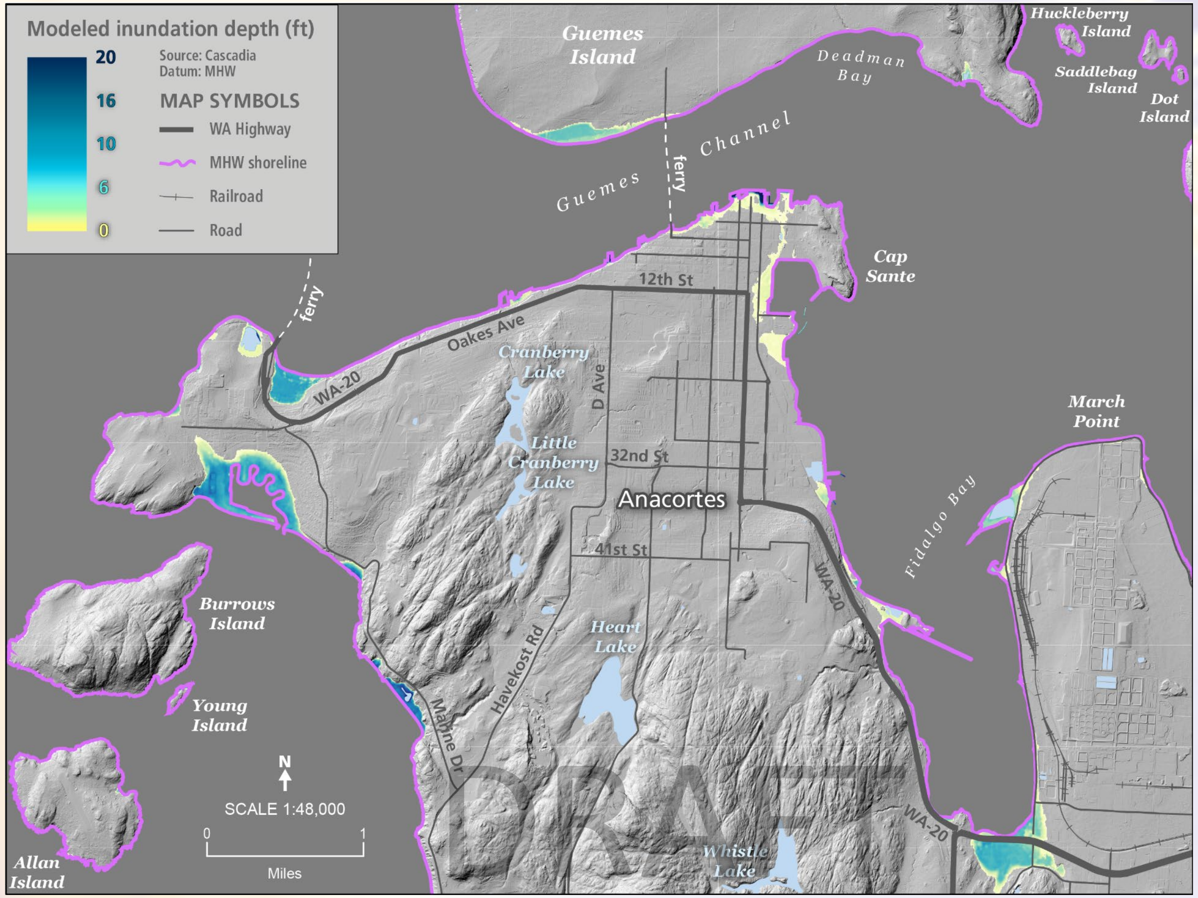
- **30 fathoms** (55 meters or 180 feet)

Local Source (ships at sea)

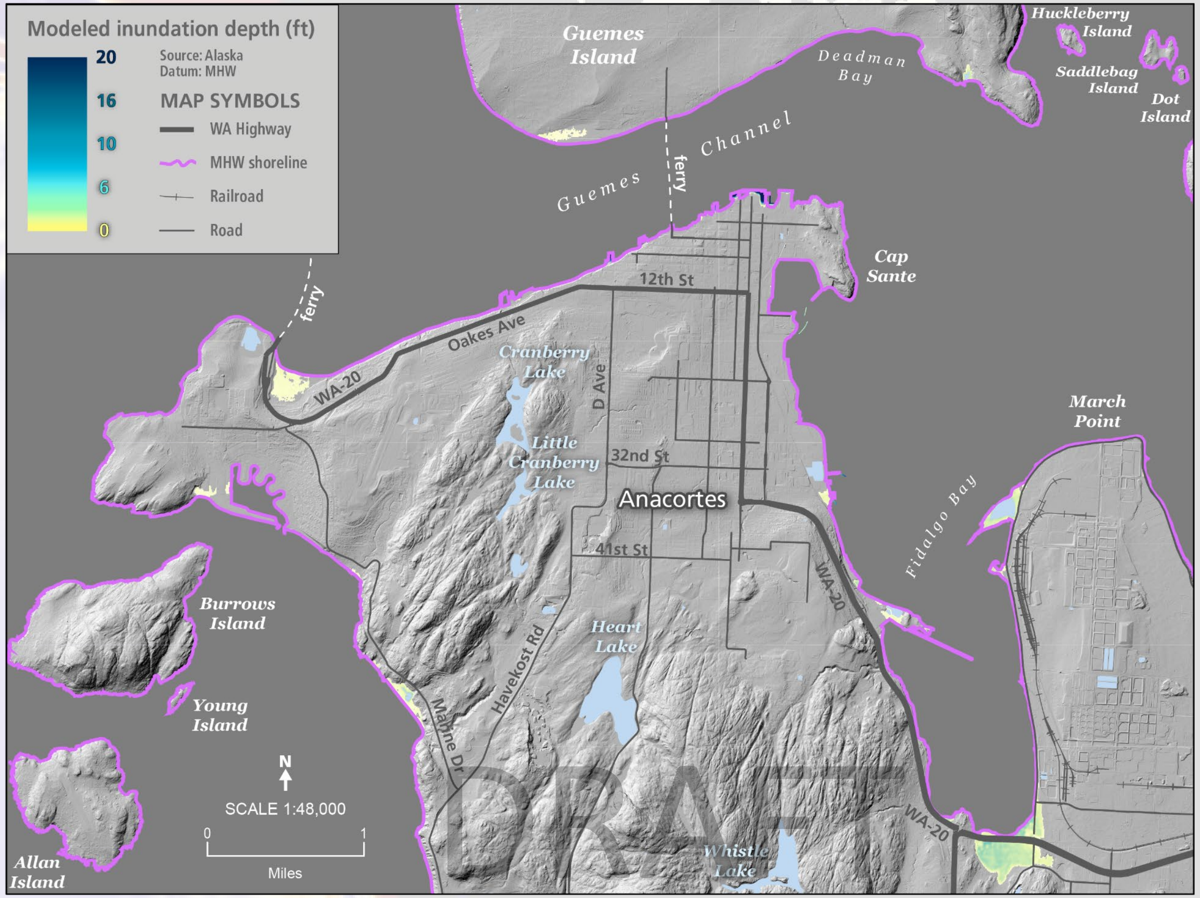
- **100 fathoms** (183 meters or 600 feet)



Cascadia



Alaska

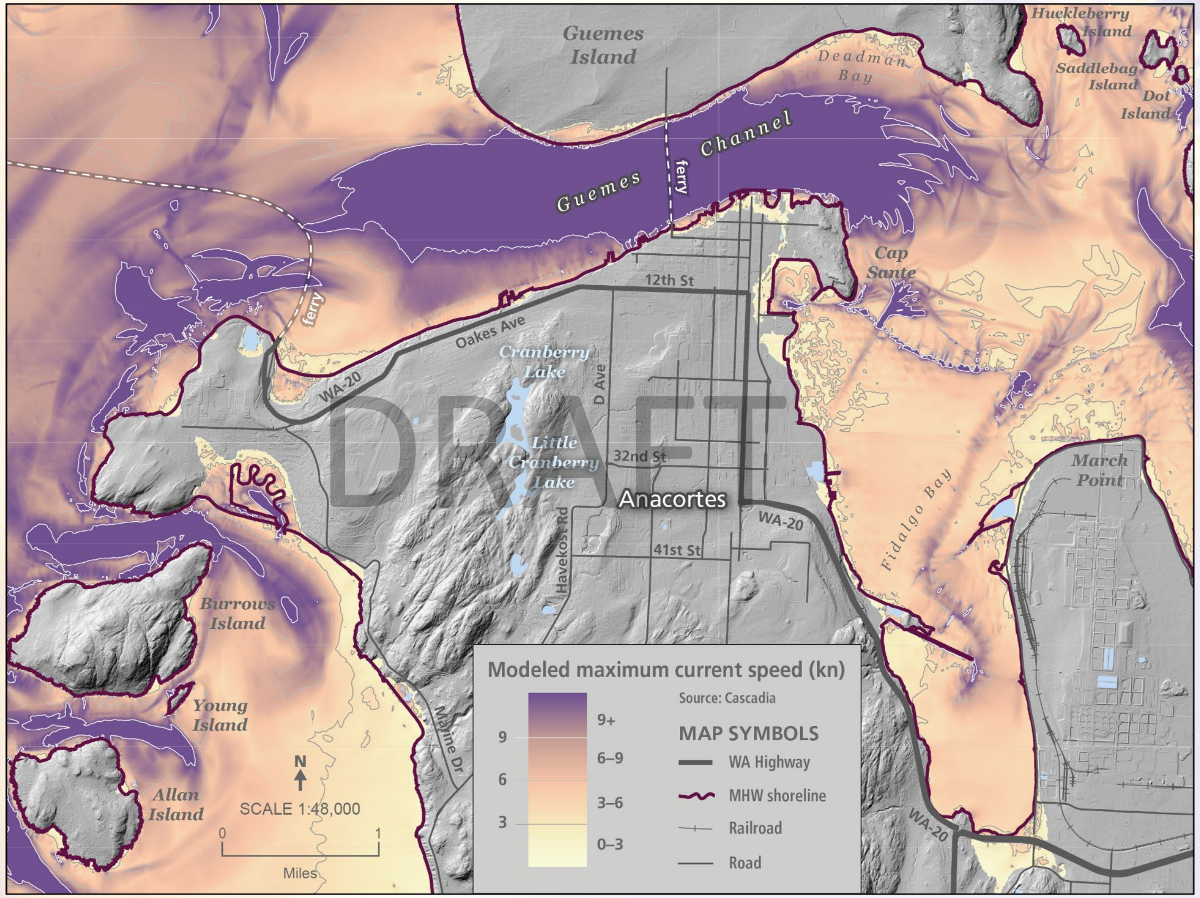


Overview of modeled inundation flooding depths over land

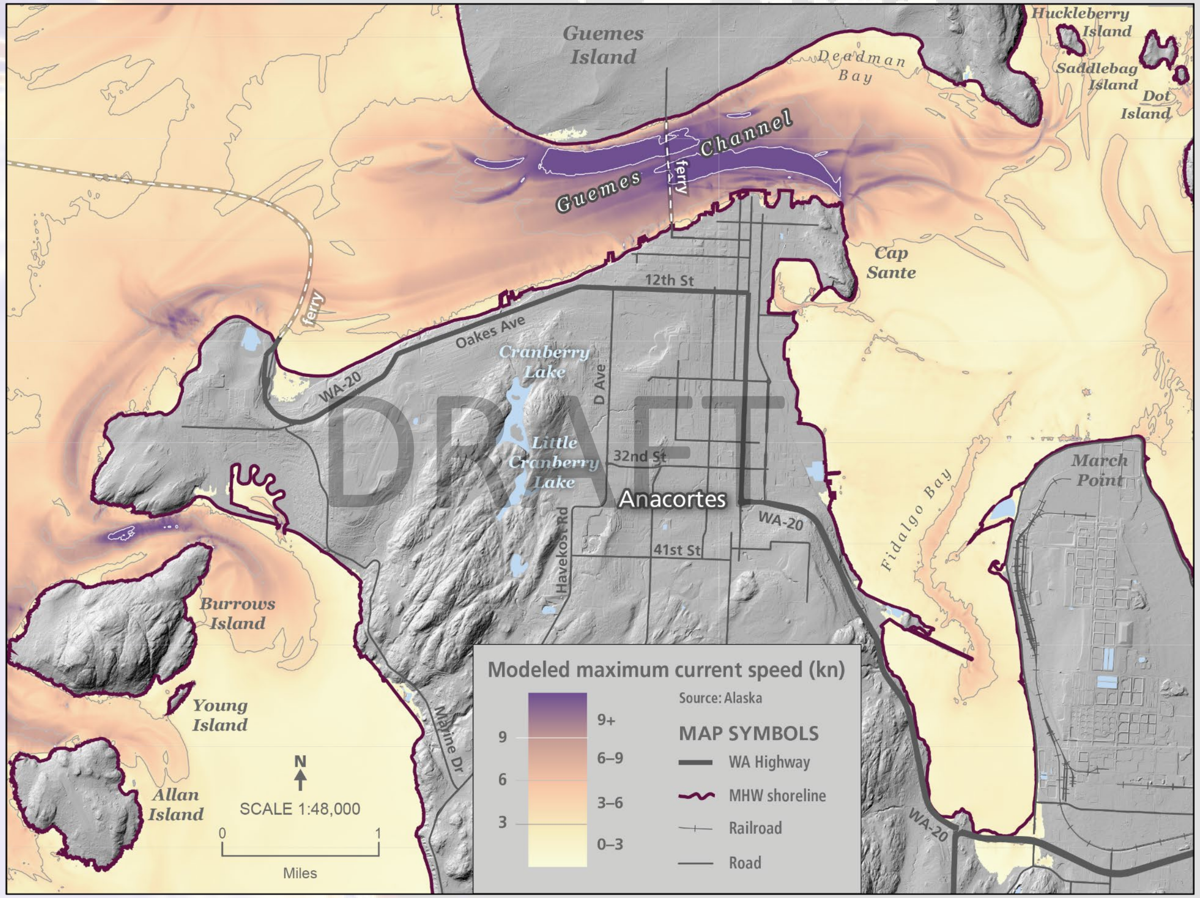
Tidal datum: mean high water

Model resolution: 1/3rd arc-second (10m)

Cascadia



Alaska

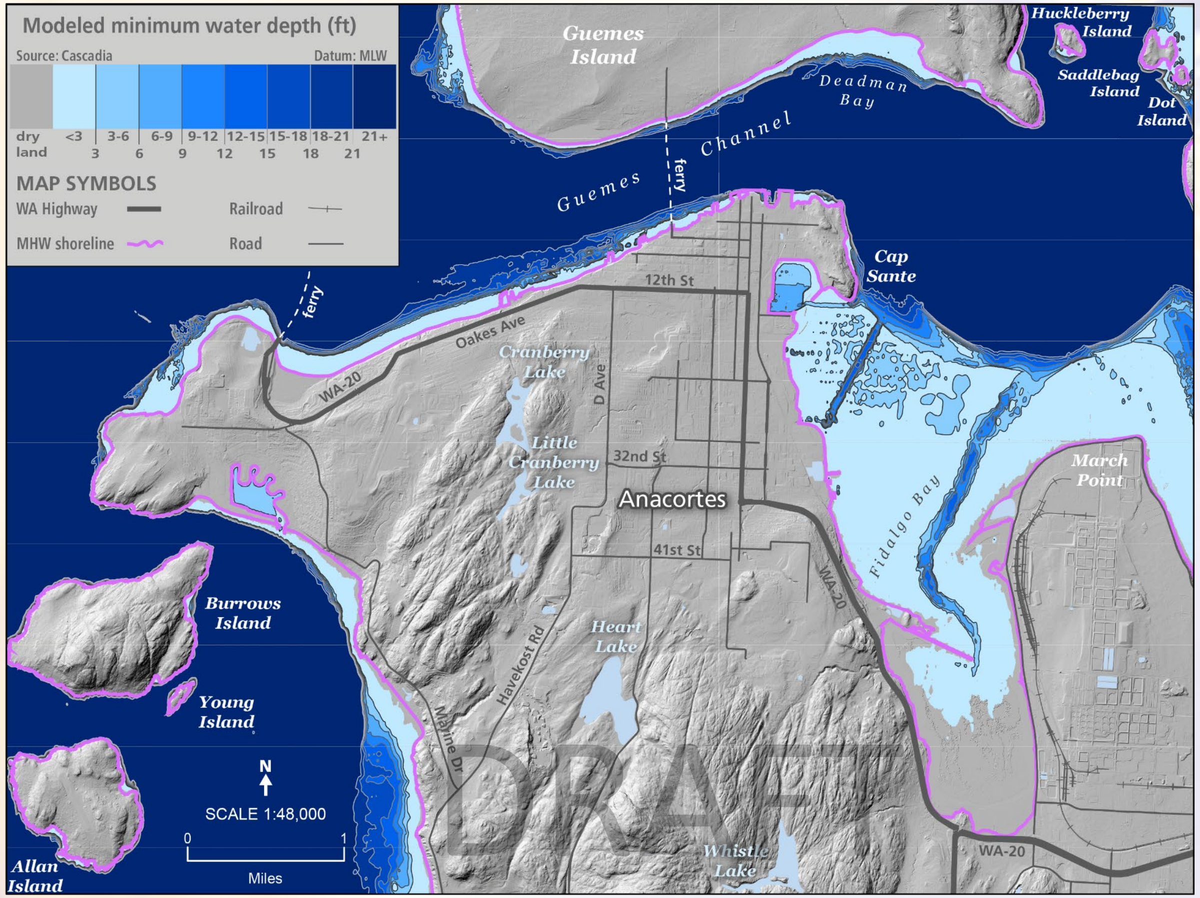


Overview of modeled current speeds

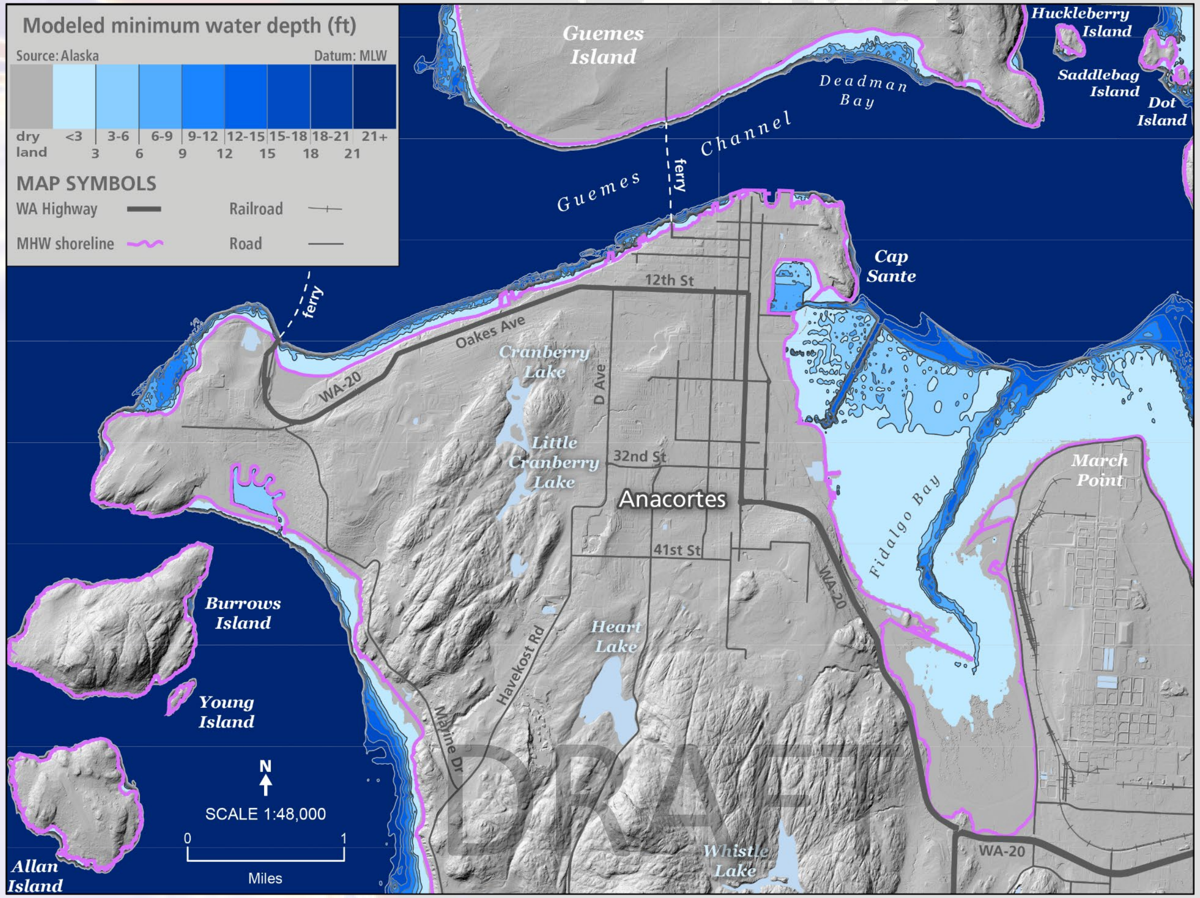
Tidal datum: maximum values generated between the mean high water and mean low water runs

Model resolution: 1/3rd arc-second (10m)

Cascadia



Alaska



Overview of modeled minimum water depths (maximum drawdown)

Tidal datum: mean low water

Model resolution: 1/3rd arc-second (10m)