SCIENCE BEHIND TSUNAMIS: MODELING AND MAP PRODUCTION

Tsunami Roadshow
April 10th-13th, 2018

Daniel Eungard, LG
Washington Geological Survey

Looking past. Looking forward.

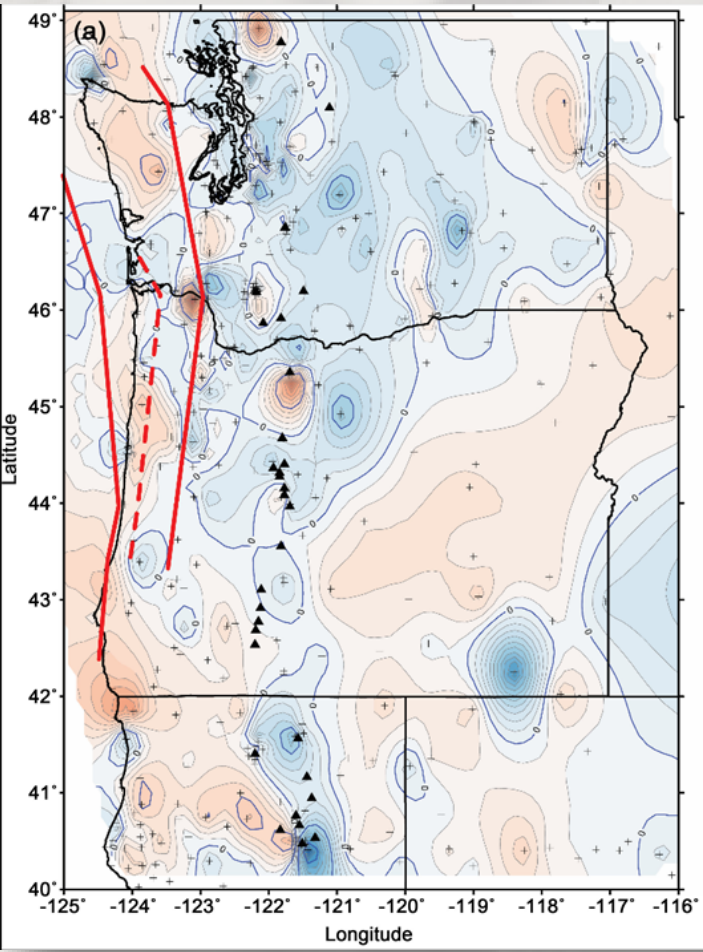
Using our knowledge of past events captured in the geologic record how can we predict what might happen next?

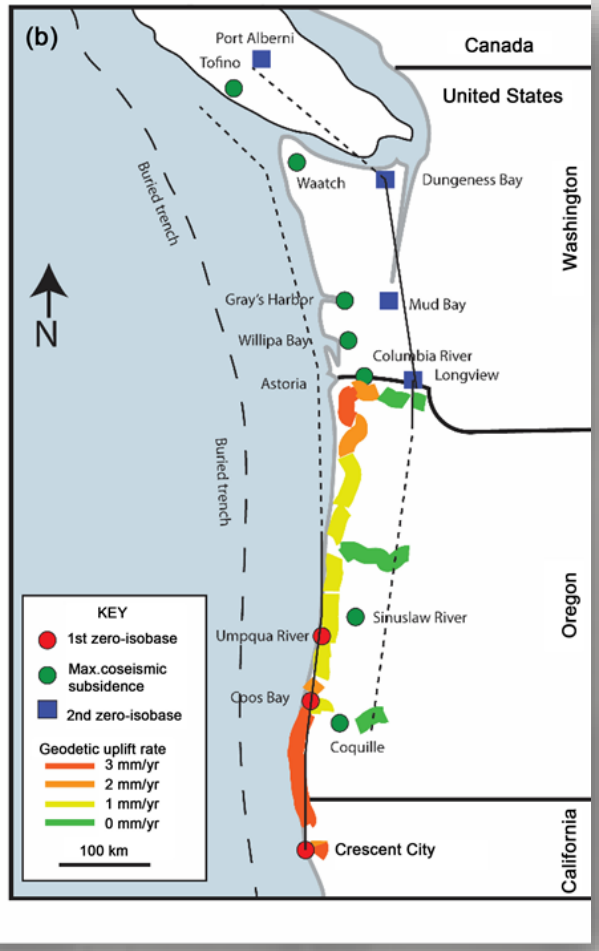
- Recurrence interval and extent of paleo-tsunami deposits
- Plate convergence rates, accumulating strain
- Earthquake and tsunami observations from other subduction zones

Common terms/definitions

- Inundation extent– farthest extent of tsunami wave on land
- Inundation depth– maximum height of water above ground surface
- Current velocity– Speed of water flowing from tsunami (static tide)
- Arrival time– Time since earthquake; arrival of the first wave (typically the time the inundation starts rather than reaches it's peak)

Modern geodetic uplift



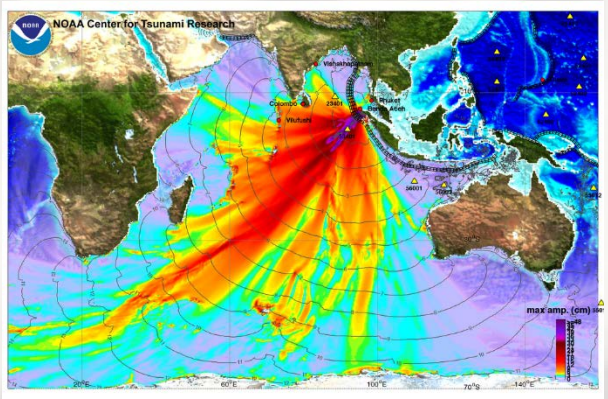


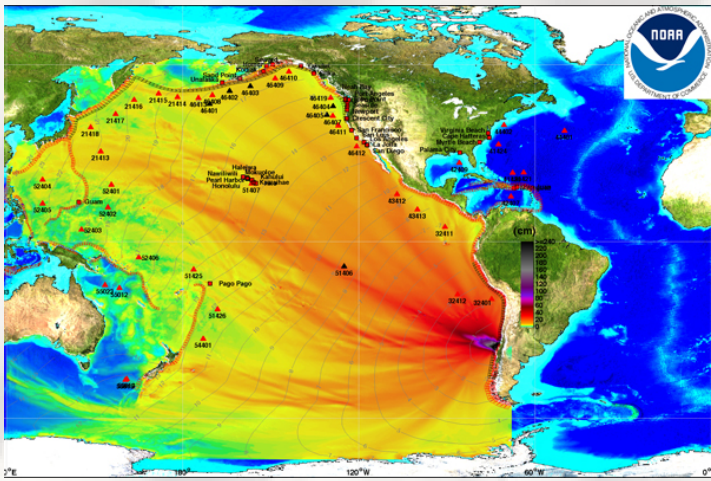
[Example: Tohoku cumulative gps displacement]

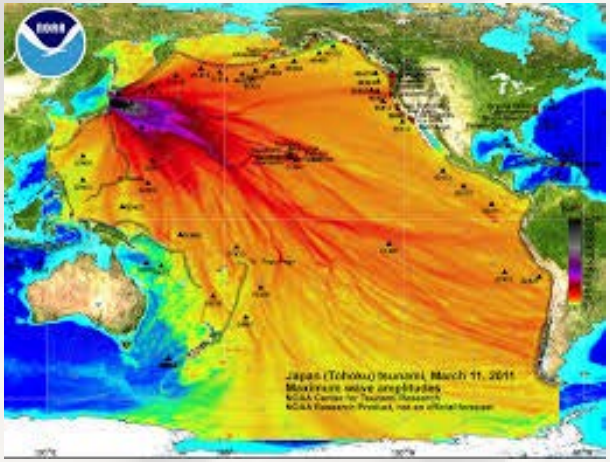
Cruikshank, K. and Peterson, C. (2017) Late Stage Interseismic Strain Interval, Cascadia Subduction Zone Margin, USA and Canada. Open Journal of Earthquake Research, 6, 1-34

Recent events at other subduction zones

- 2004 Sumatra, Mw 9.1, 225,000 fatalities
- 2010 Chile, Mw 8.8, 525 fatalities
- 2011 Tohoku, Mw 9.0, 15,890 fatalities







*All images from NOAA-PMEL

Cascadia earthquake scenarios

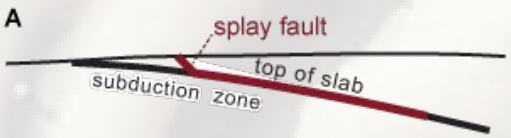
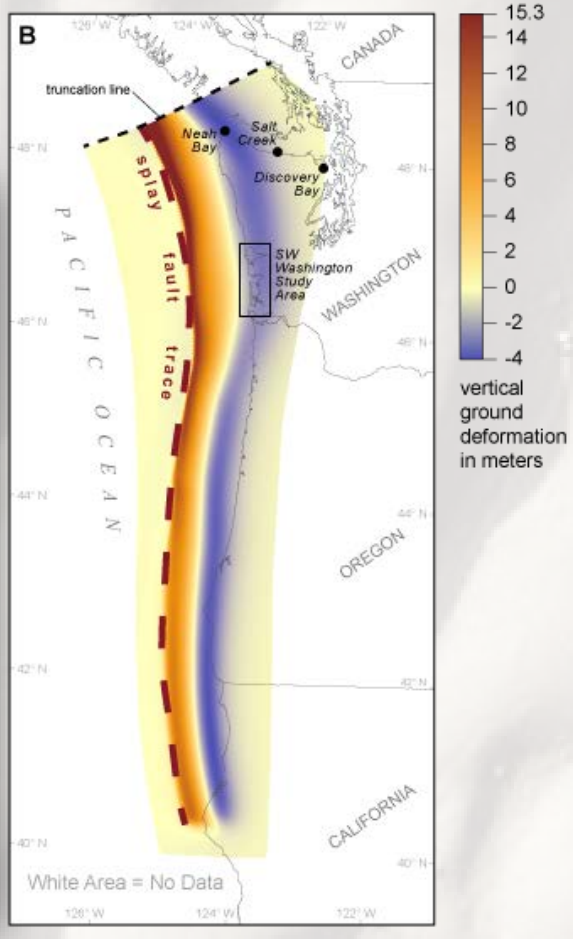


Table 3. Cascadia earthquake source parameters used to define 15 rupture scenarios. Logic tree branch weights shown in parentheses. Total scenario weight listed in right column.

Earthquake Size	Interevent Time (yrs)	Fault Geometry	Slip Range (m)		M_w	Scenario Name	Total Weight
			Maximum	Average			
Extra Extra Large (0.025)	1,200	Splay fault (0.8)	36–44	18–22	~9.1	XXL 1	0.02
		Shallow buried rupture (0.1)	36–44	18–22	~9.2	XXL 2	0.0025
		Deep buried rupture (0.1)	36–44	18–22	~9.1	XXL 3	0.0025
Extra Large (0.025)	1,050–1,200	Splay fault (0.8)	35–44	17–22	~9.1	XL 1	0.02
		Shallow buried rupture (0.1)	35–44	17–22	~9.2	XL 2	0.0025
		Deep buried rupture (0.1)	35–44	17–22	~9.1	XL 3	0.0025
Large (0.16)	650–800	Splay fault (0.8)	22–30	11–15	~9.0	L 1	0.128
		Shallow buried rupture (0.1)	22–30	11–15	~9.1	L 2	0.016
		Deep buried rupture (0.1)	22–30	11–15	~9.0	L 3	0.016
Medium (0.53)	425–525	Splay fault (0.6)	14–19	7–9	~8.9	M 1	0.318*
		Shallow buried rupture (0.2)	14–19	7–9	~9.0	M 2	0.106
		Deep buried rupture (0.2)	14–19	7–9	~8.9	M 3	0.106
Small (0.26)	275–300	Splay fault (0.4)	9–11	4–5	~8.7	SM 1	0.104
		Shallow buried rupture (0.3)	9–11	4–5	~8.8	SM 2	0.078
		Deep buried rupture (0.3)	9–11	4–5	~8.7	SM 3	0.078

*Scenario M1 carries the highest weight and represents the "most likely" event in our analysis.



Witter, Robert C., et al. "Simulated tsunami inundation for a range of Cascadia megathrust earthquake scenarios at Bandon, Oregon, USA." *Geosphere* 9.6 (2013): 1783-1803.

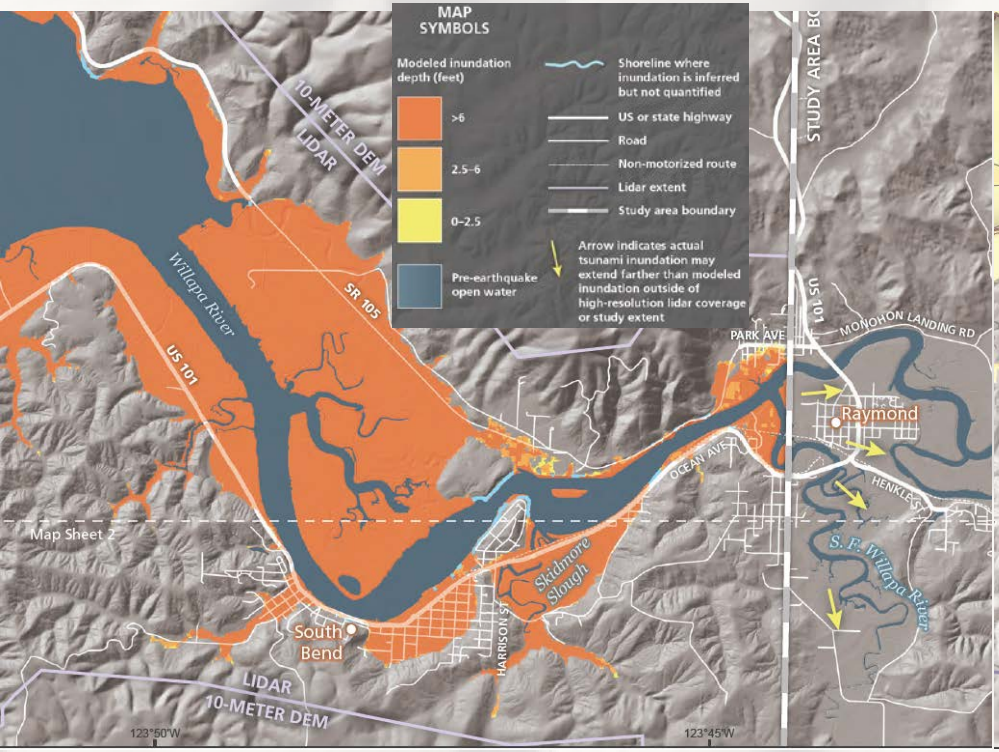
Modeling the next Cascadia

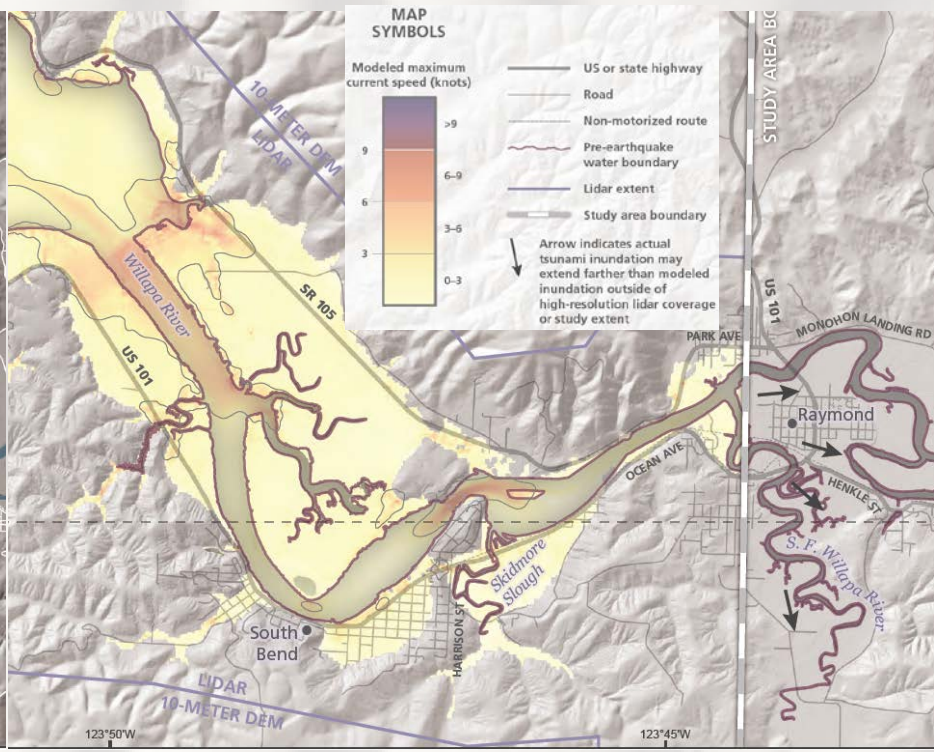
- Modeling programs predict wave behavior based on earthquake source and local topography
- Creates estimates of inundation extent, depth, timing, and current velocities

Slides 8-14: L1 scenario animations of wave arrival for all of Washington, Pacific County, Grays Harbor County, Hoh Reservation, La Push, Port Angeles, and Port Townsend

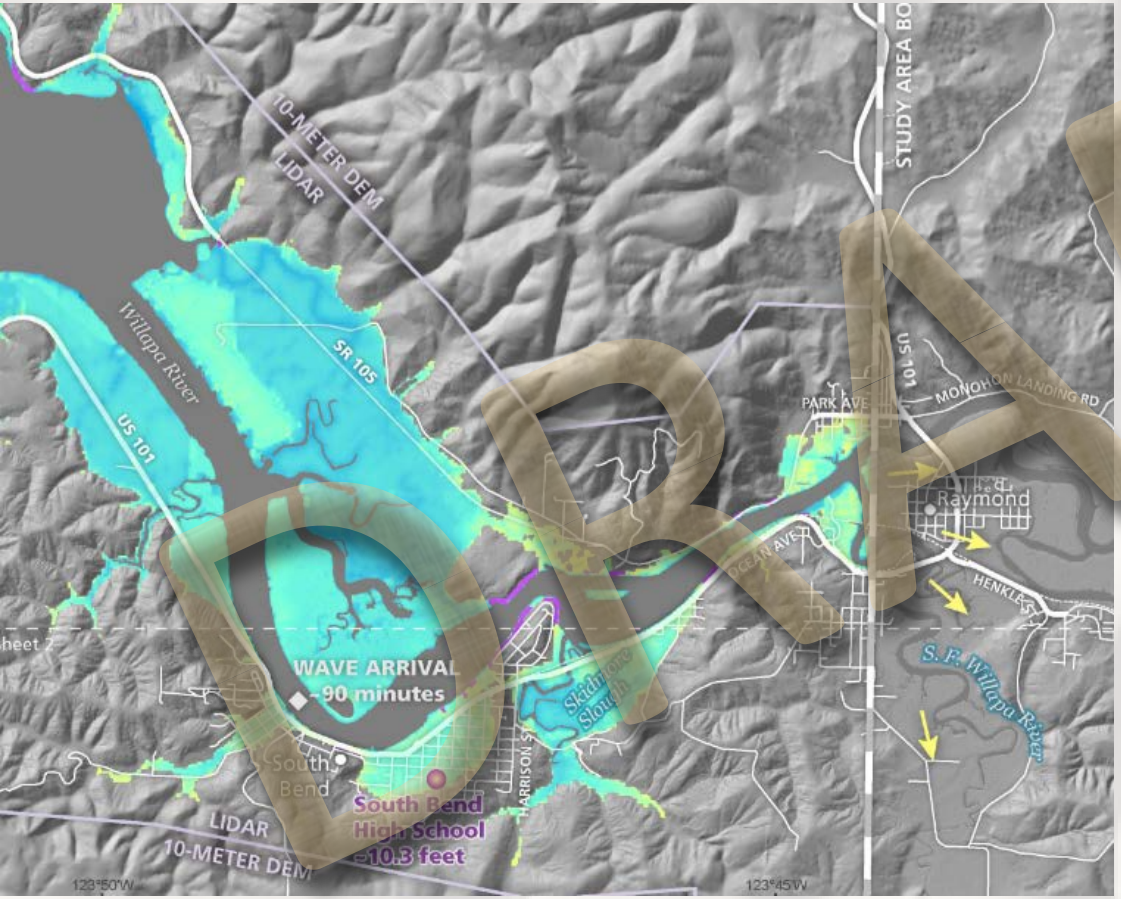
Removed as animations are not publicly available at this time.

Raymond / South Bend area specifics





Raymond / South Bend area specifics



MAP SYMBOLS

Modeled inundation depth (feet)

60
50
40
30
20
10
0

Pre-earthquake open water

Point elevation

Shoreline where inundation is inferred but not quantified

US or state highway

Road

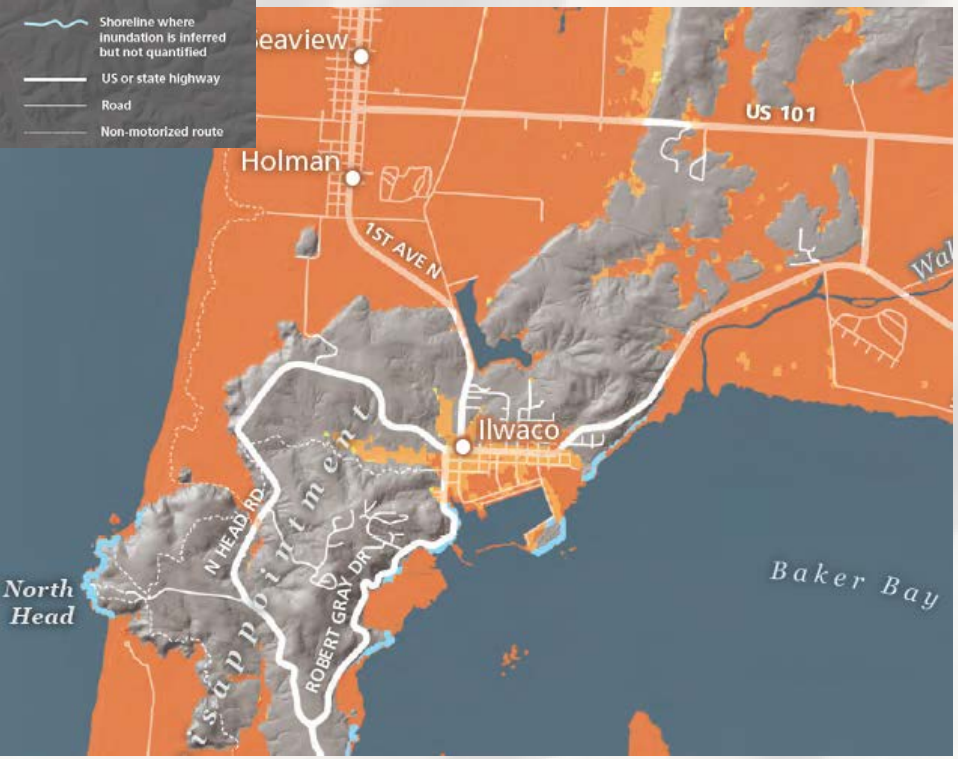
Non-motorized route

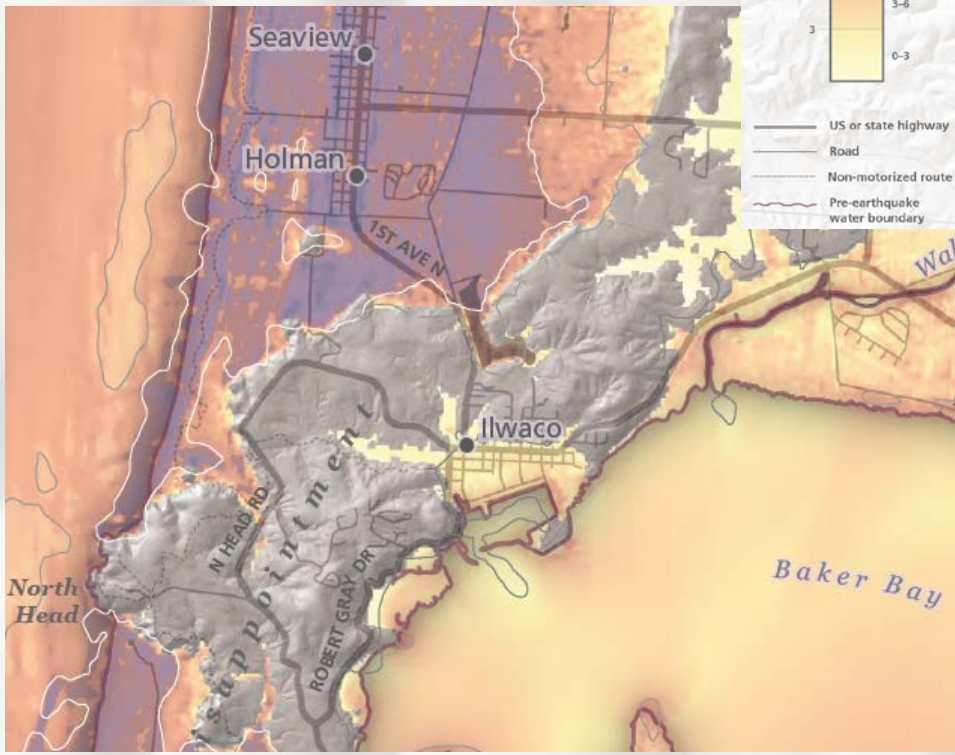
Lidar extent

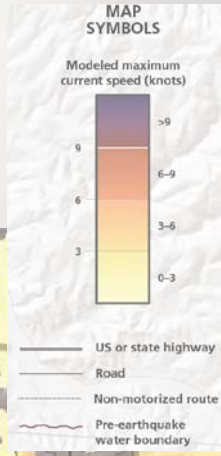
Study area boundary

Arrow indicates actual tsunami inundation may extend farther than modeled inundation outside of high-resolution lidar coverage or study extent

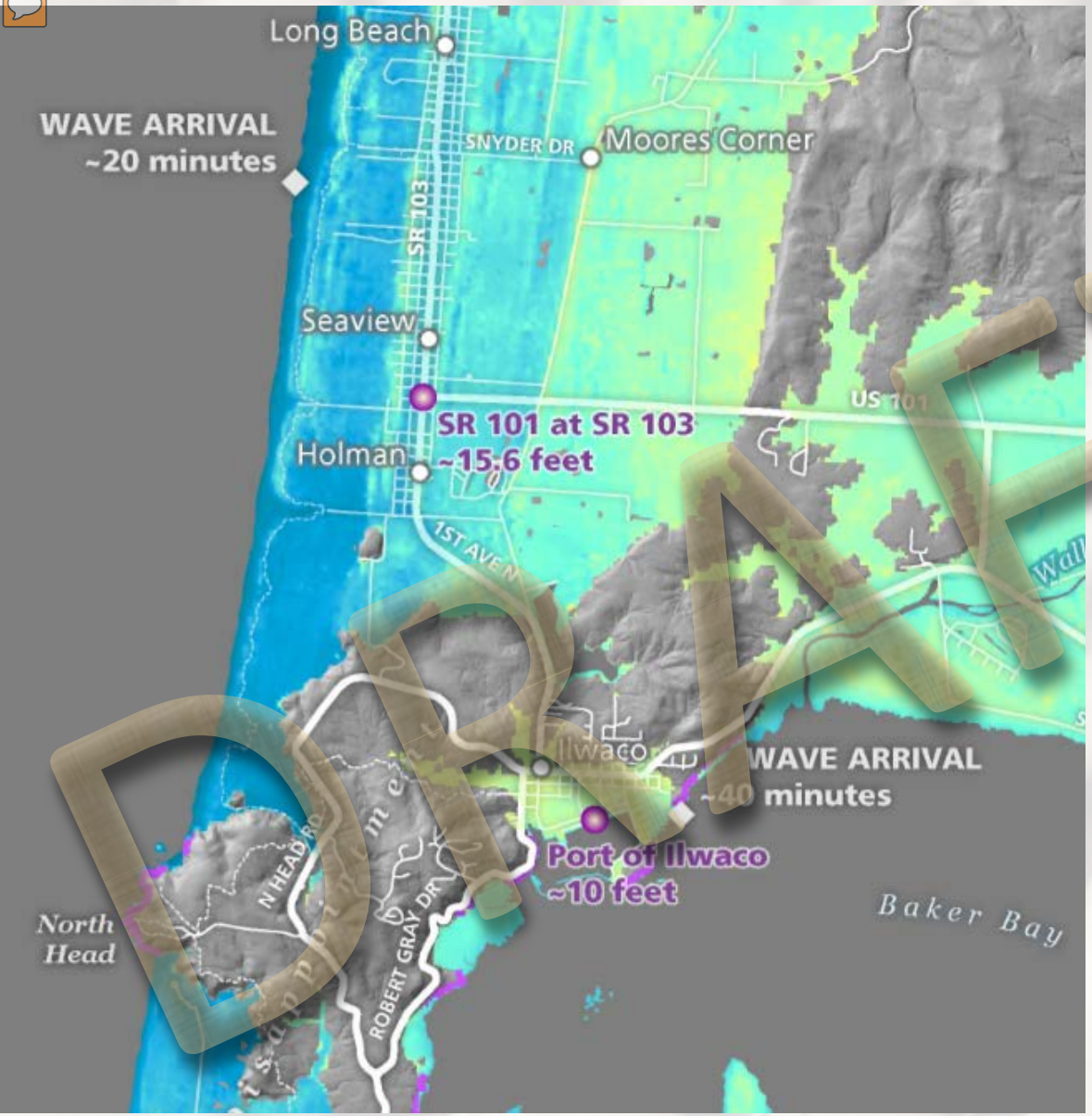
Ilwaco area specifics







Ilwaco area specifics



MAP SYMBOLS

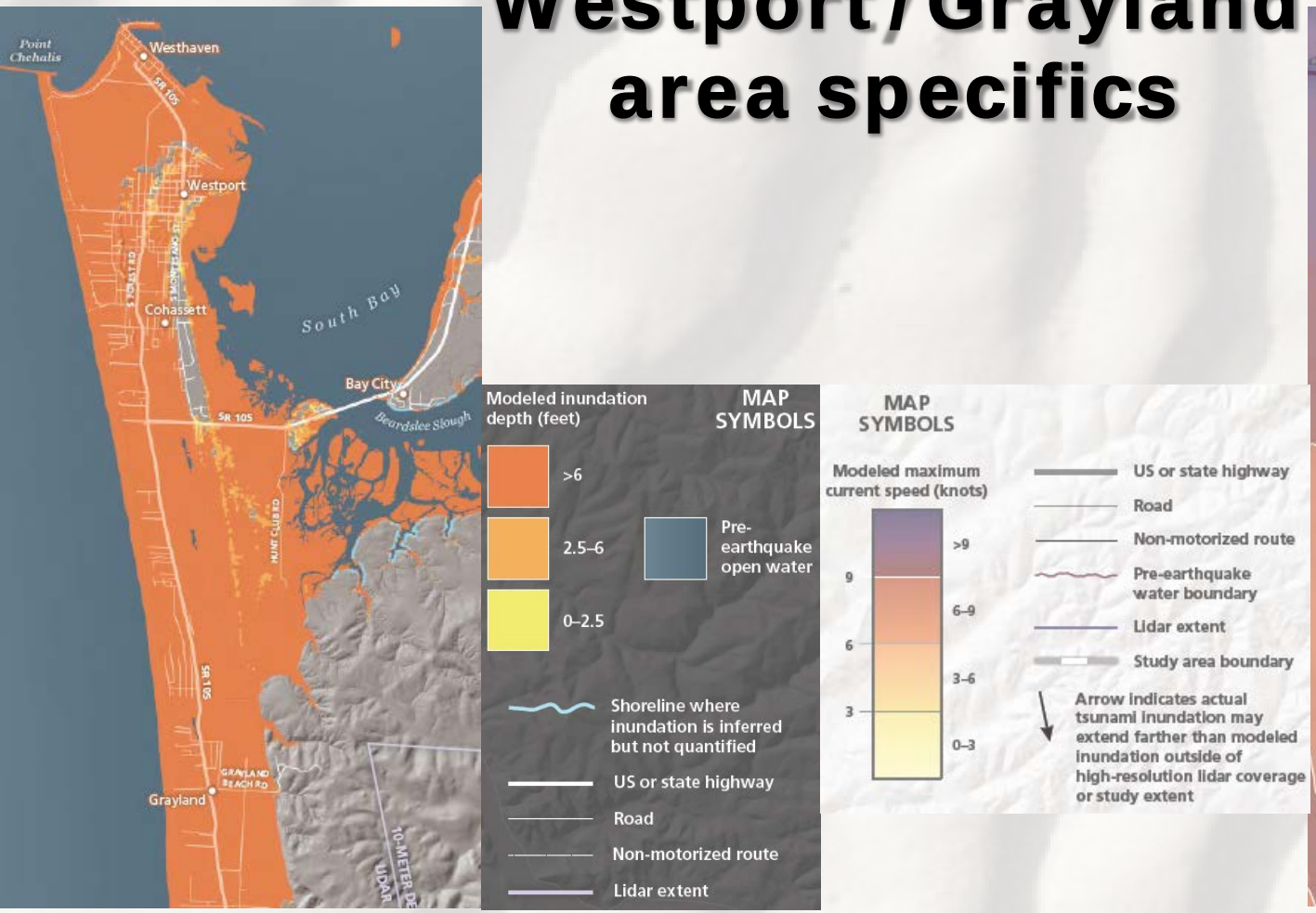
Modeled inundation depth (feet)

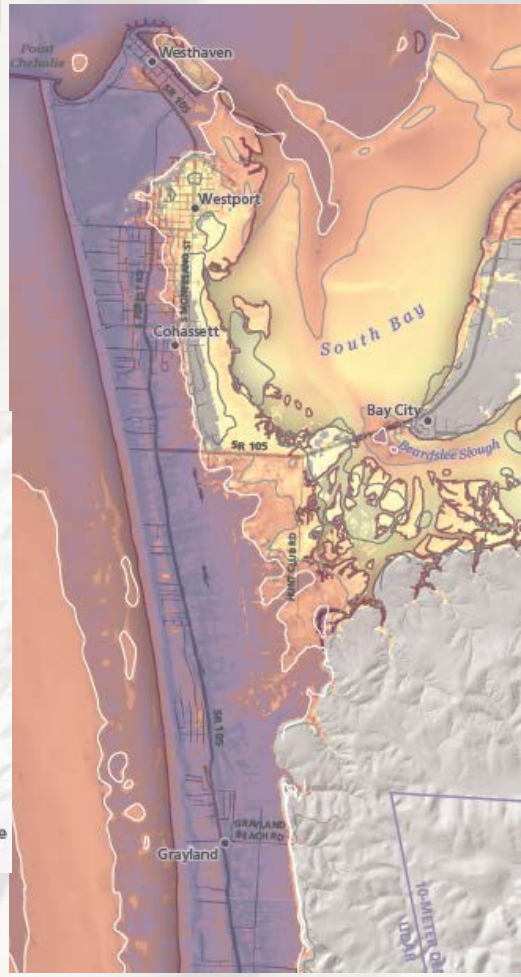
60
50
40
30
20
10
0

Pre-earthquake open water

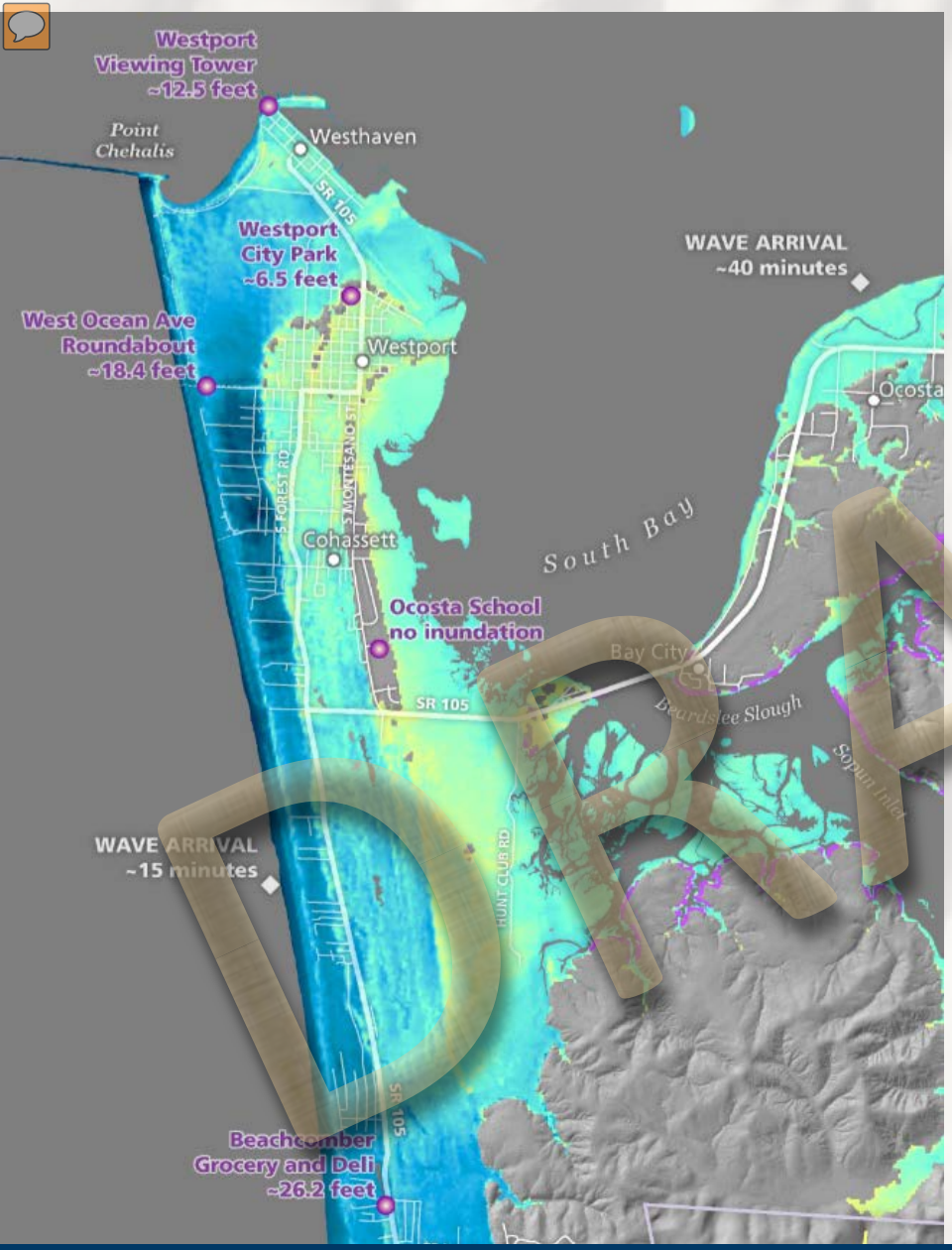
- Point elevation
- Shoreline where inundation is inferred but not quantified
- US or state highway
- Road
- Non-motorized route
- Lidar extent
- Study area boundary
- Arrow indicates actual tsunami inundation may extend farther than modeled inundation outside of high-resolution lidar coverage or study extent

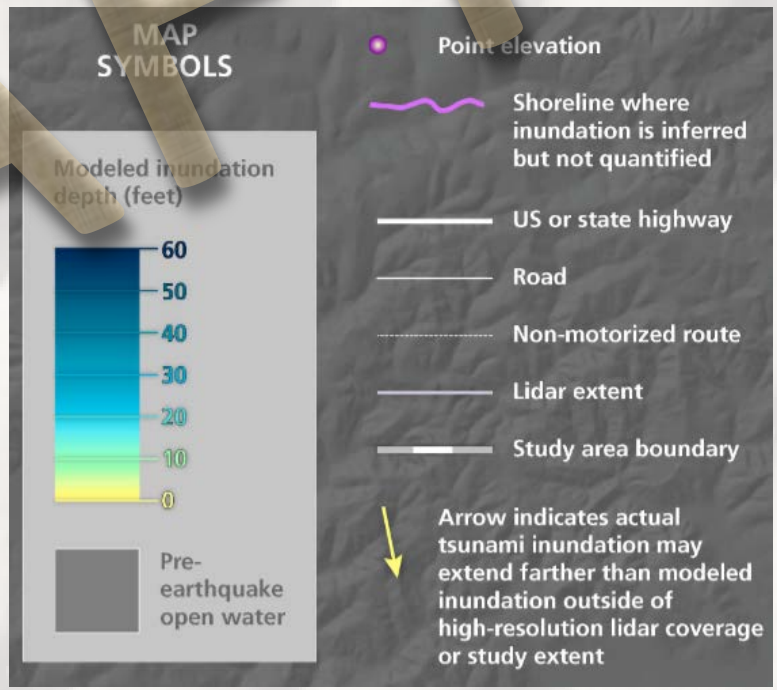
Westport/Grayland area specifics





Westport/Grayland area specifics





Ocean Shores area specifics

MAP SYMBOLS

Modeled inundation depth (feet)

- >6
- 2.5–6
- 0–2.5
- Pre-earthquake open water

- Shoreline where inundation is inferred but not quantified
- US or state highway
- Road
- Non-motorized route
- Lidar extent
- Study area boundary

Arrow indicates actual tsunami inundation may extend farther than modeled inundation outside of high-resolution lidar coverage or study extent

MAP SYMBOLS

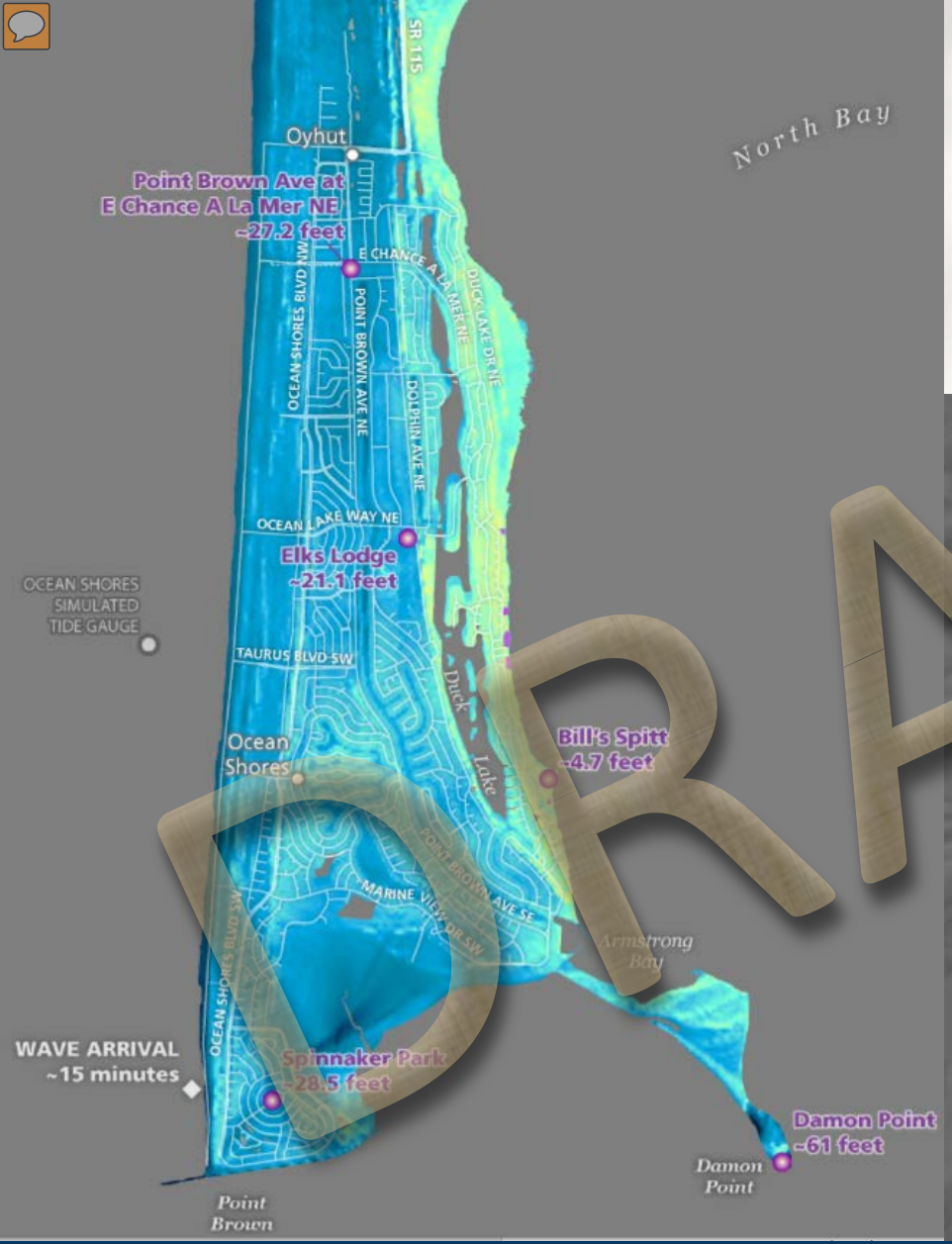
Modeled maximum current speed (knots)

- >9
- 6–9
- 3–6
- 0–3

- US or state highway
- Road
- Non-motorized route
- Pre-earthquake water boundary
- Lidar extent
- Study area boundary

Arrow indicates actual tsunami inundation may extend farther than modeled inundation outside of high-resolution lidar coverage or study extent

Ocean Shores area specifics



MAP SYMBOLS

Modeled inundation depth (feet)

60
50
40
30
20
10
0

Pre-earthquake open water

Point elevation

Shoreline where inundation is inferred but not quantified

US or state highway

Road

Non-motorized route

Lidar extent

Study area boundary

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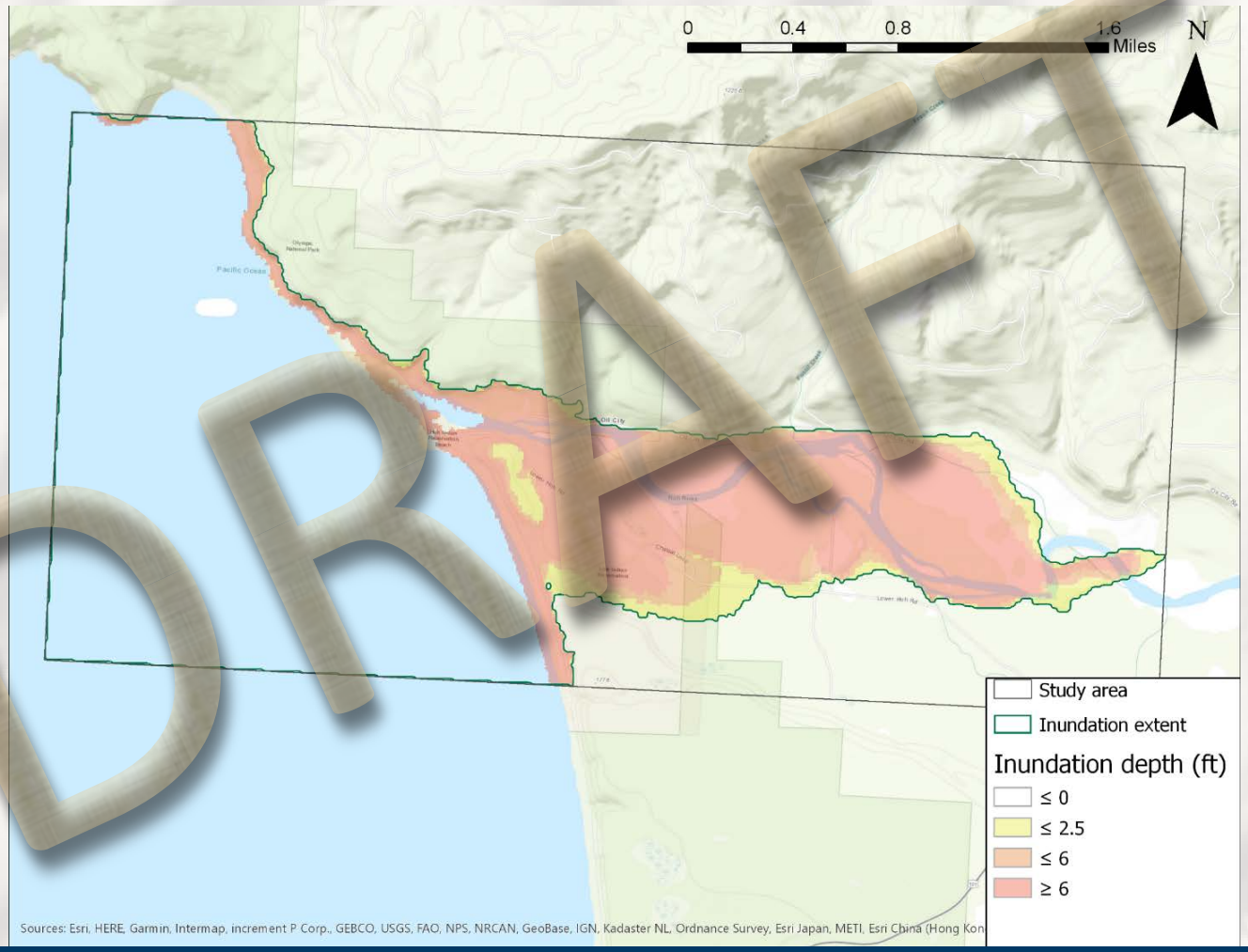
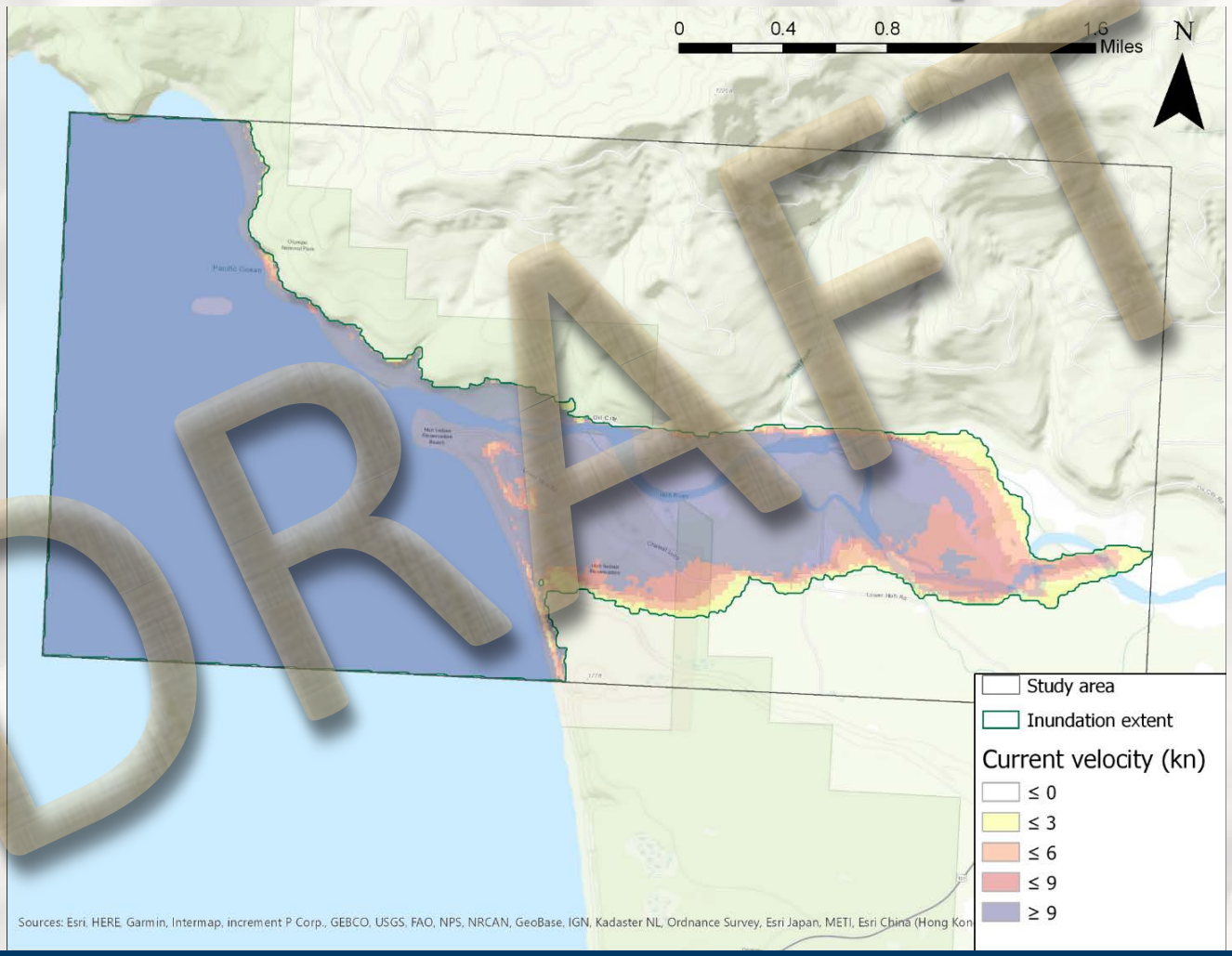
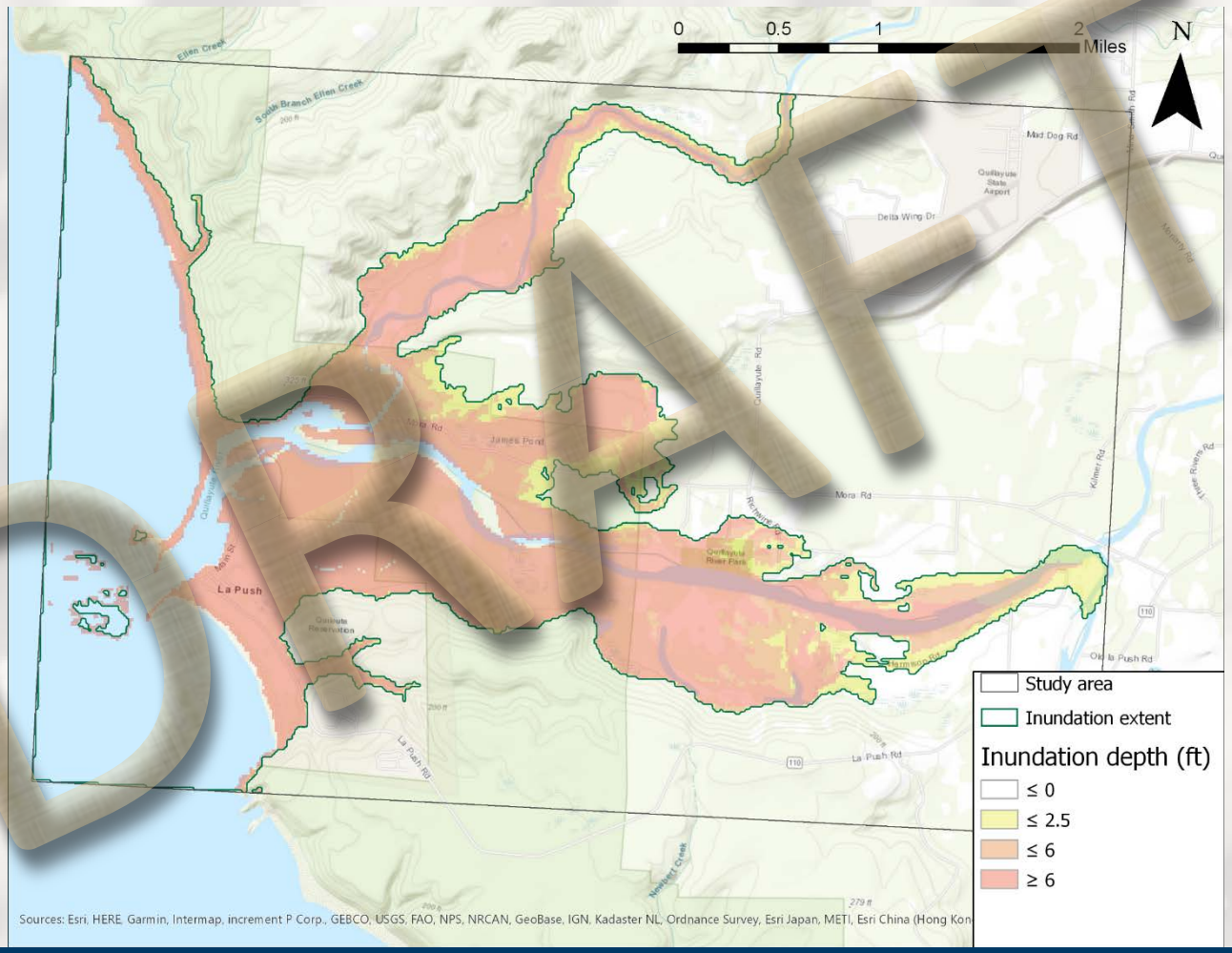
Hoh Reservation area specifics



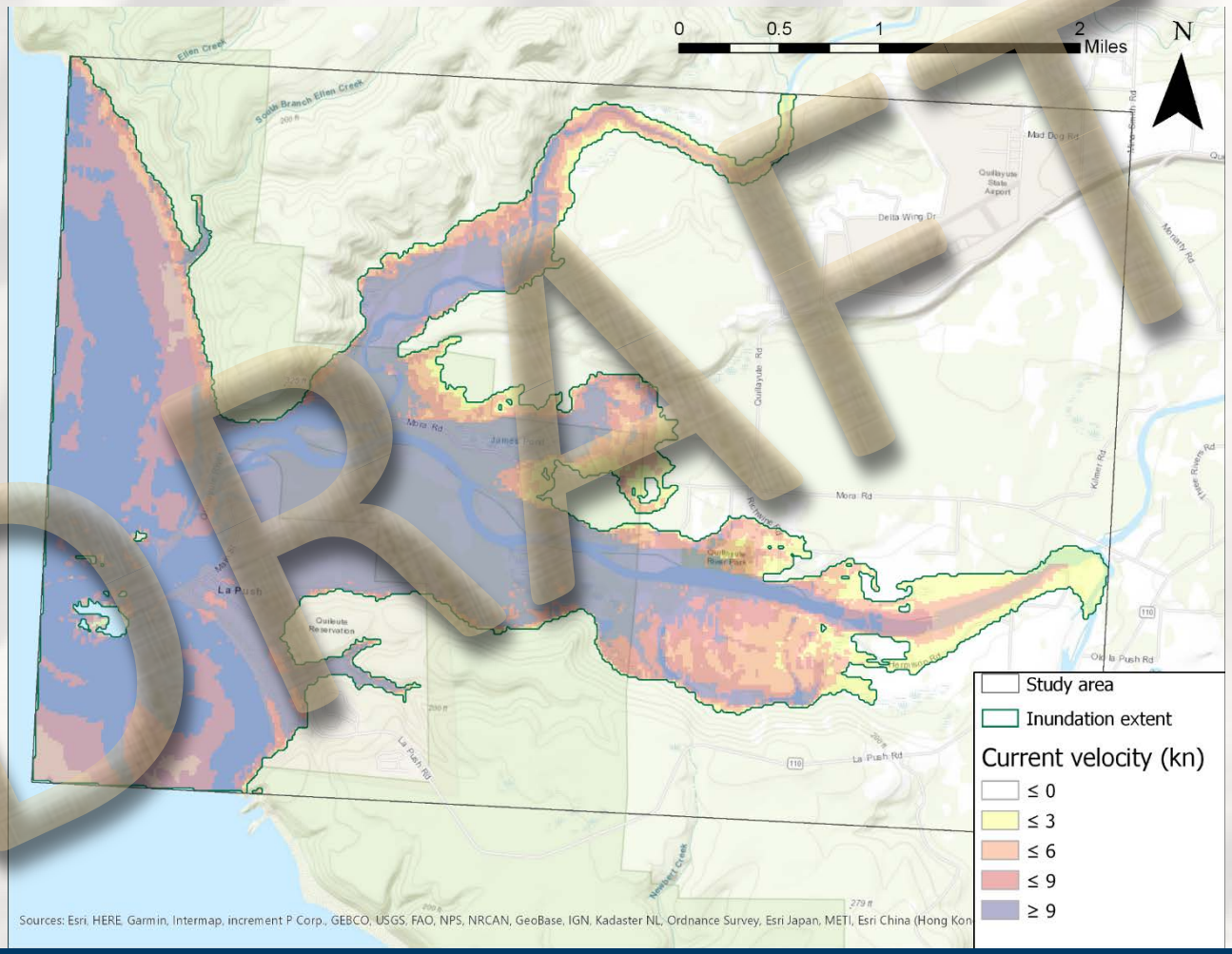
Hoh Reservation area specifics



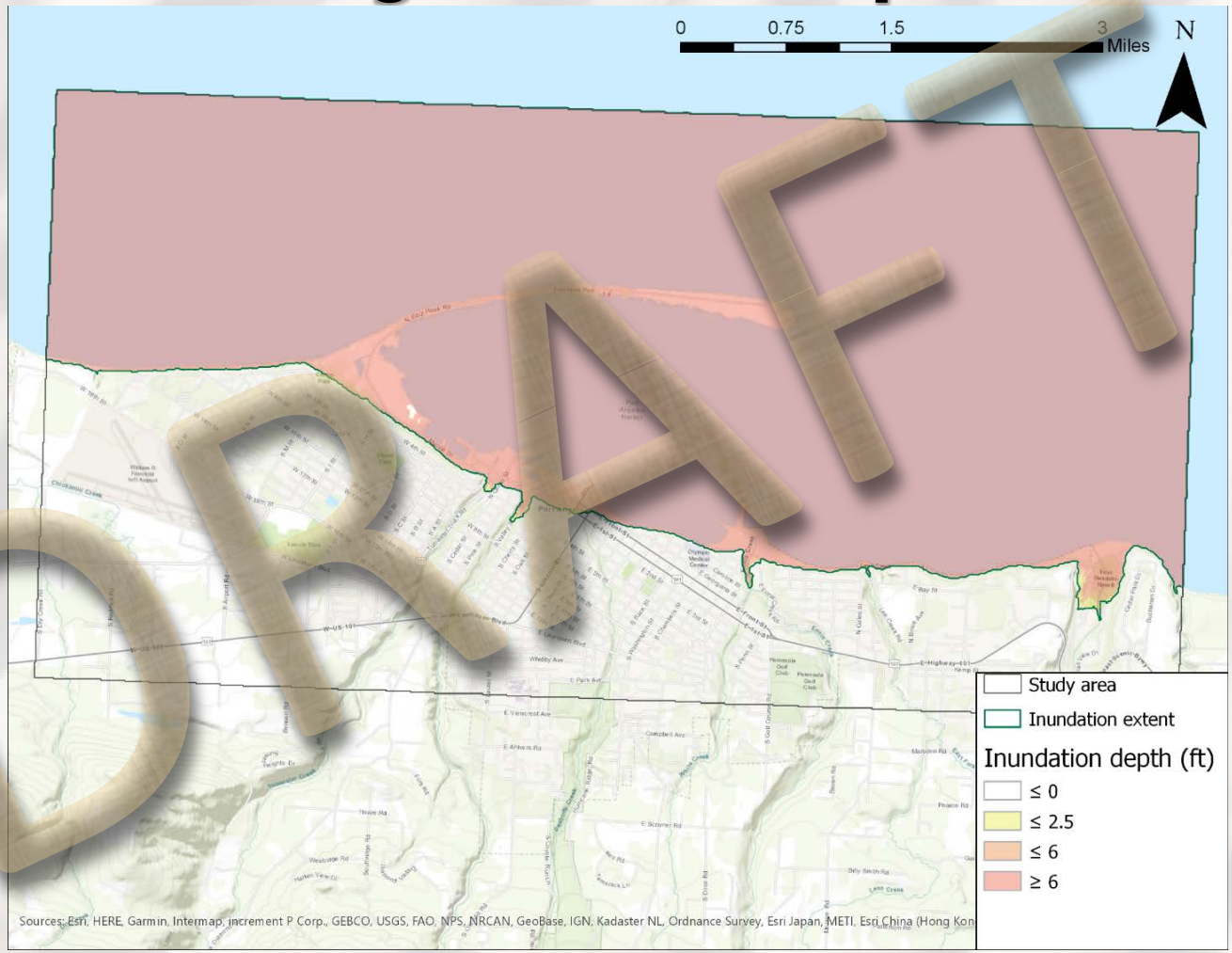
La Push area specifics



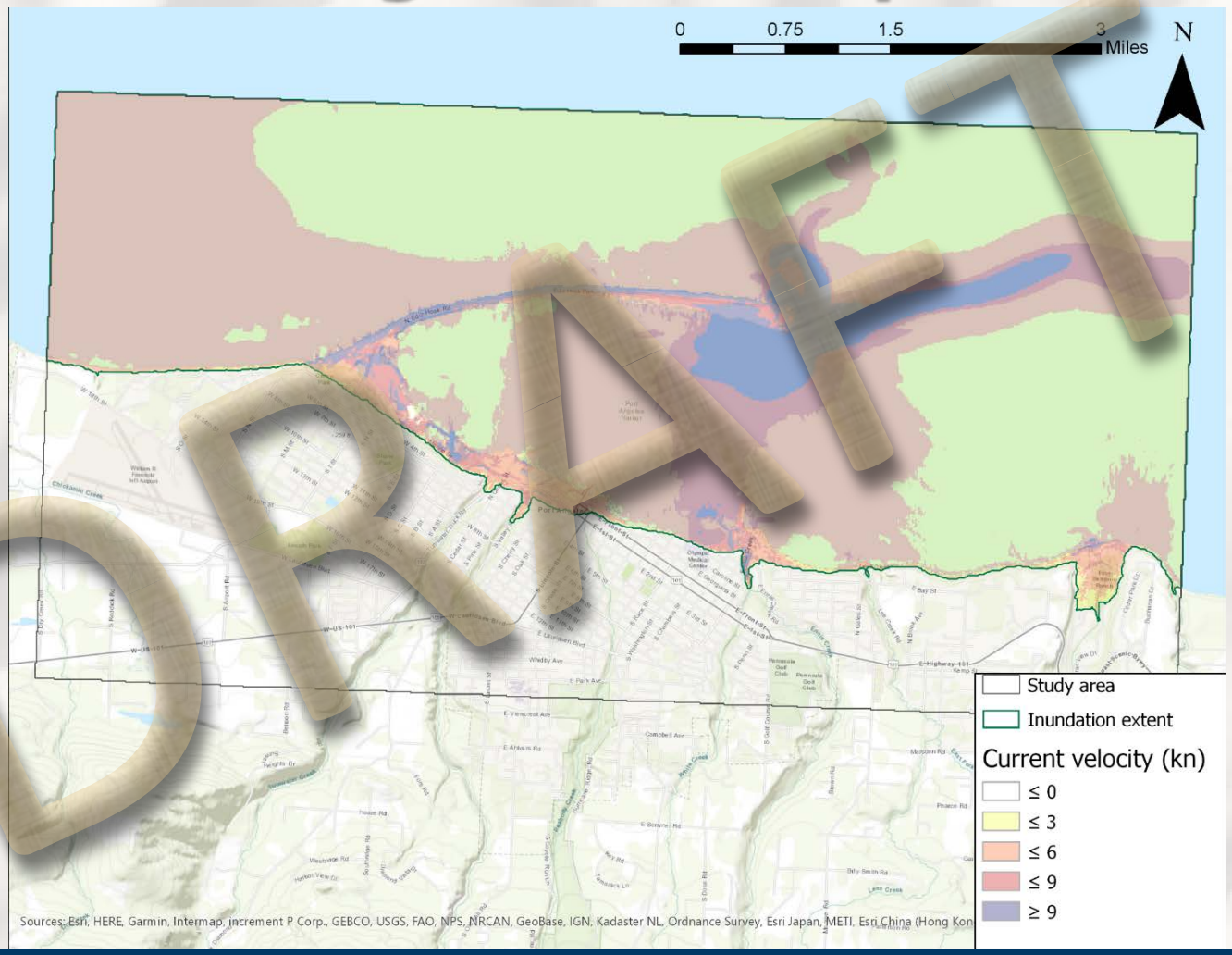
La Push area specifics



Port Angeles area specifics

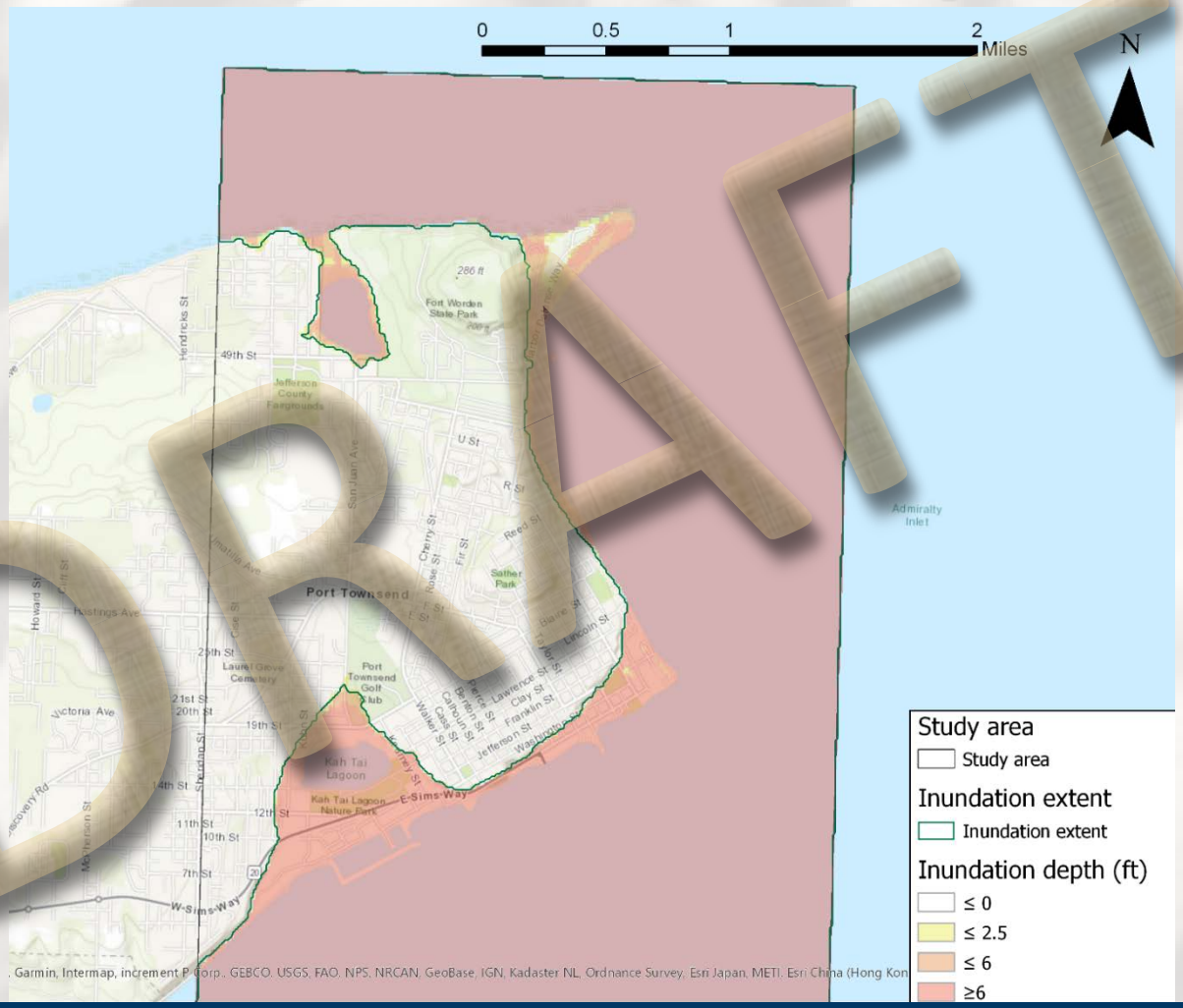


Port Angeles area specifics

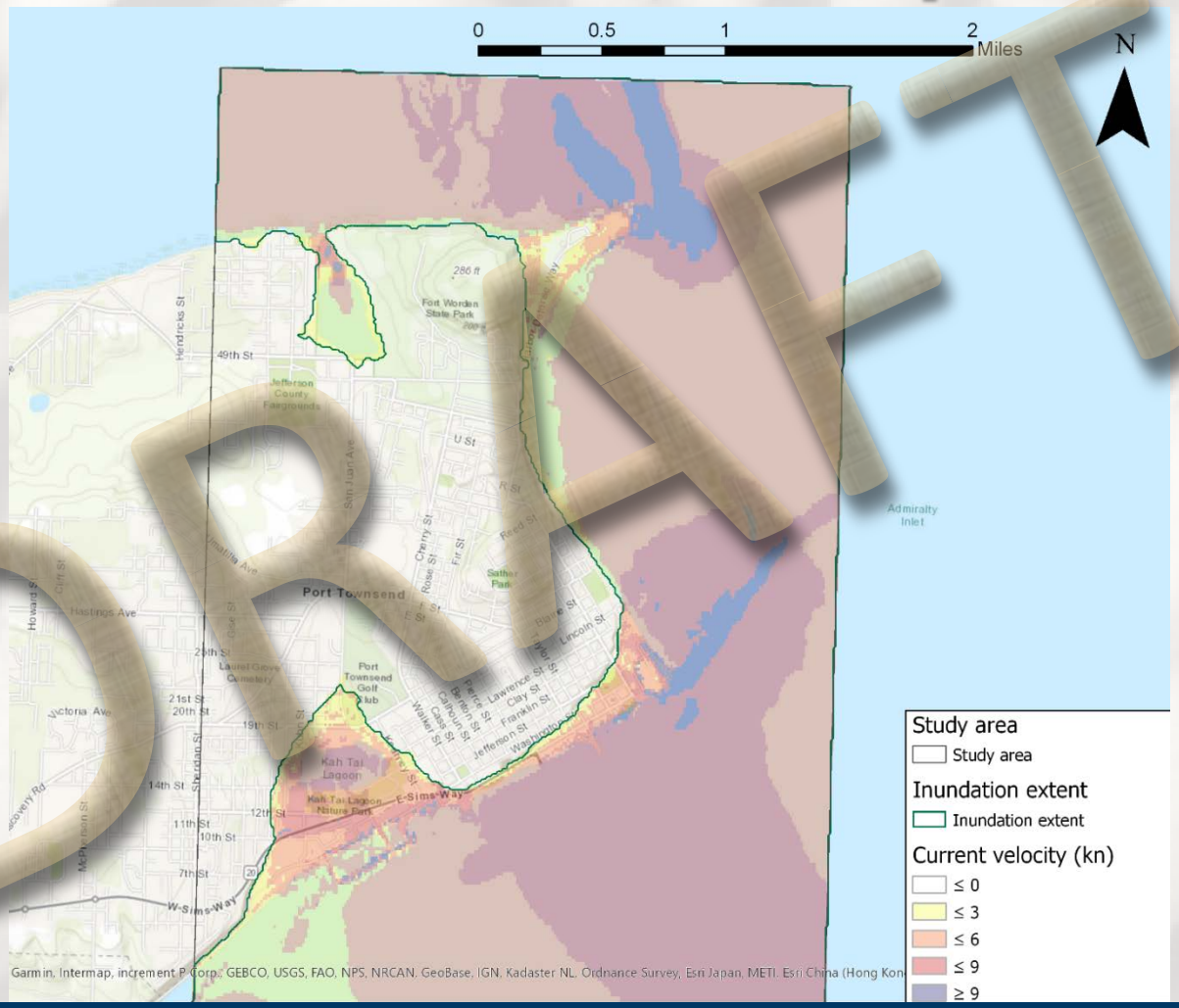


Port Angeles walk map

Port Townsend area specifics



Port Townsend area specifics



Port Townsend walk map

WGS Information

Google: Washington Geology Portal

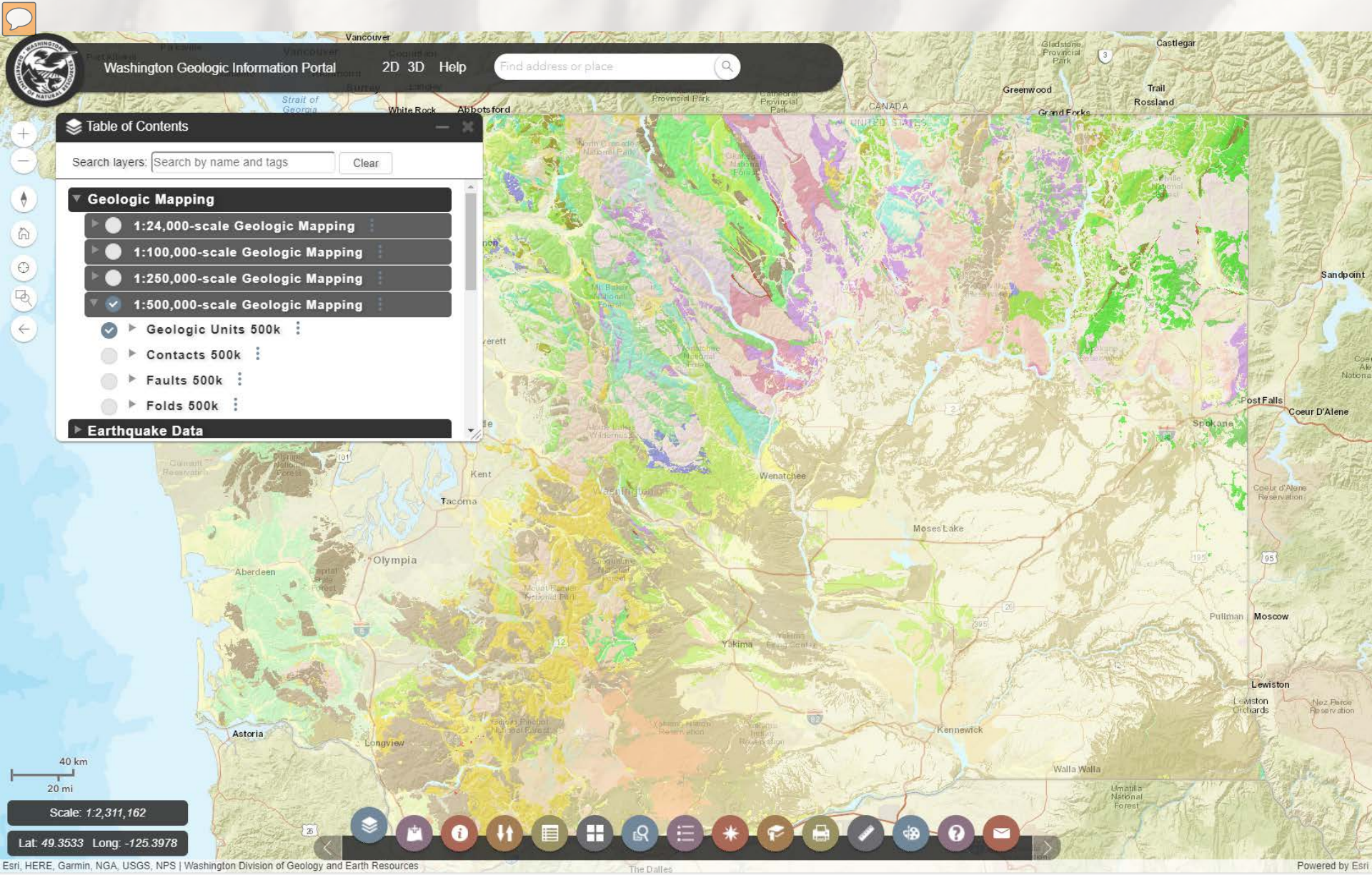
https://geologyportal.dnr.wa.gov/

Google: Washington Tsunami

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

Google: Washington Geology Mobile

https://www.dnr.wa.gov/mobilegeology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1:500,000-scale Geologic Mapping
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Contacts 500k
Faults 500k
Folds 500k
Earthquake Data
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Abbotsford
White Rock
CANADA
Castlegar
Greenwood
Trail
Rossland
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Post Falls
Coeur D'Alene
Spokane
Wenatchee
Moses Lake
Kent
Tacoma
Olympia
Aberdeen
Yakima
Pullman
Moscow
Lewiston
Kennewick
Walla Walla
Astoria
Longview
The Dalles
40 km
20 mi
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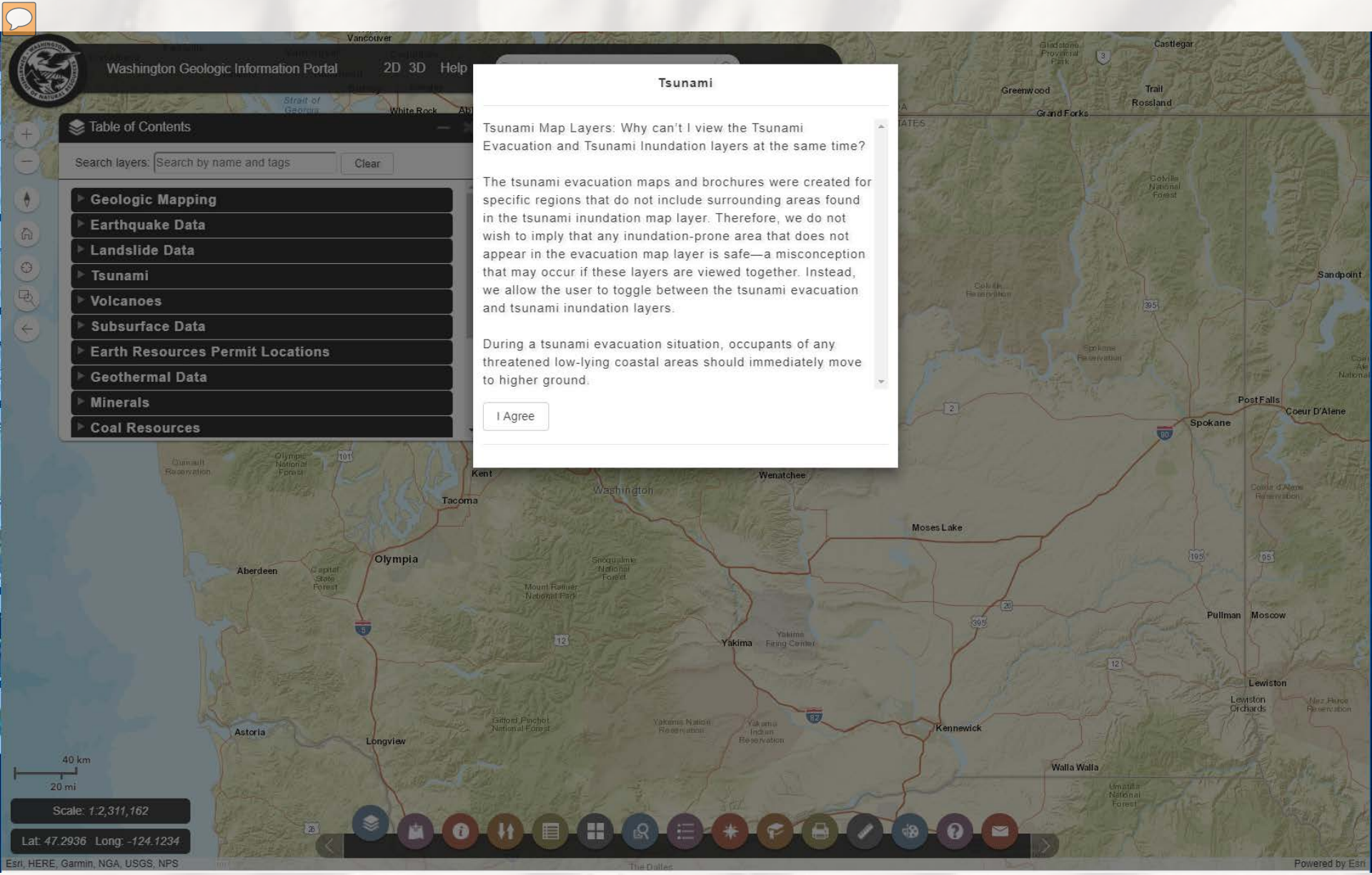
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Earth Resources Permit Locations
Geothermal Data
Minerals
Coal Resources
Tsunami
Tsunami Map Layers: Why can't I view the Tsunami Evacuation and Tsunami Inundation layers at the same time?
The tsunami evacuation maps and brochures were created for specific regions that do not include surrounding areas found in the tsunami inundation map layer. Therefore, we do not wish to imply that any inundation-prone area that does not appear in the evacuation map layer is safe—a misconception that may occur if these layers are viewed together. Instead, we allow the user to toggle between the tsunami evacuation and tsunami inundation layers.
During a tsunami evacuation situation, occupants of any threatened low-lying coastal areas should immediately move to higher ground.
I Agree
Vancouver
Castlegar
Greenwood
Trail
Rossland
Grand Forks
Sandpoint
Post Falls
Coeur D'Alene
Spokane
Kent
Tacoma
Wenatchee
Moses Lake
Olympia
Aberdeen
Yakima
Pullman
Moscow
Lewiston
Kennewick
Walla Walla
Longview
Astoria
40 km
20 mi
Scale: 1:2,311,162
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Esri, HERE, Garmin, NGA, USGS, NPS
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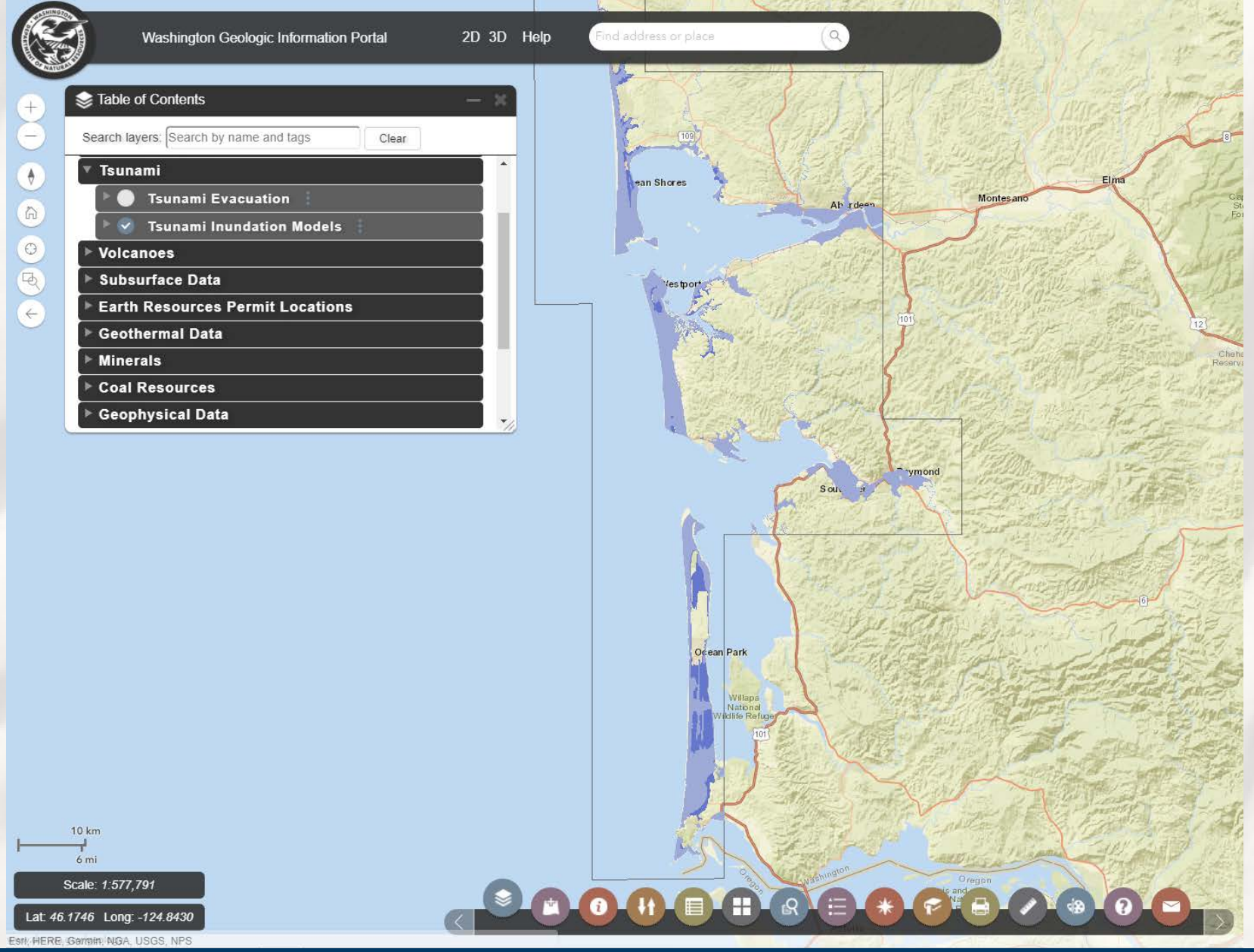
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Minerals
Coal Resources
Geophysical Data
Montesano
Elma
Raymond
Ocean Park
Willapa National Wildlife Refuge
10 km
6 mi
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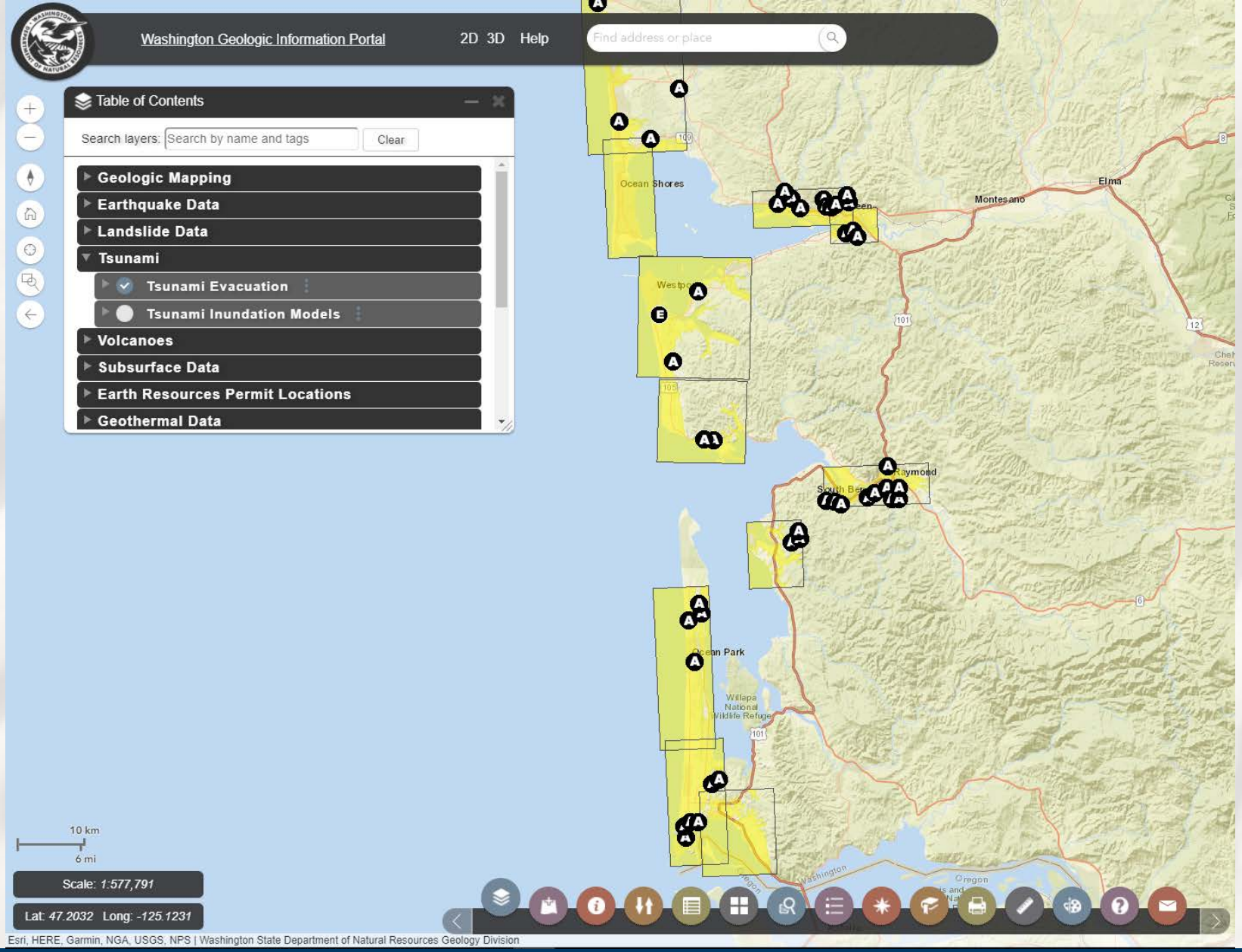
Esri, HERE, Garmin, NGA, USGS, NPS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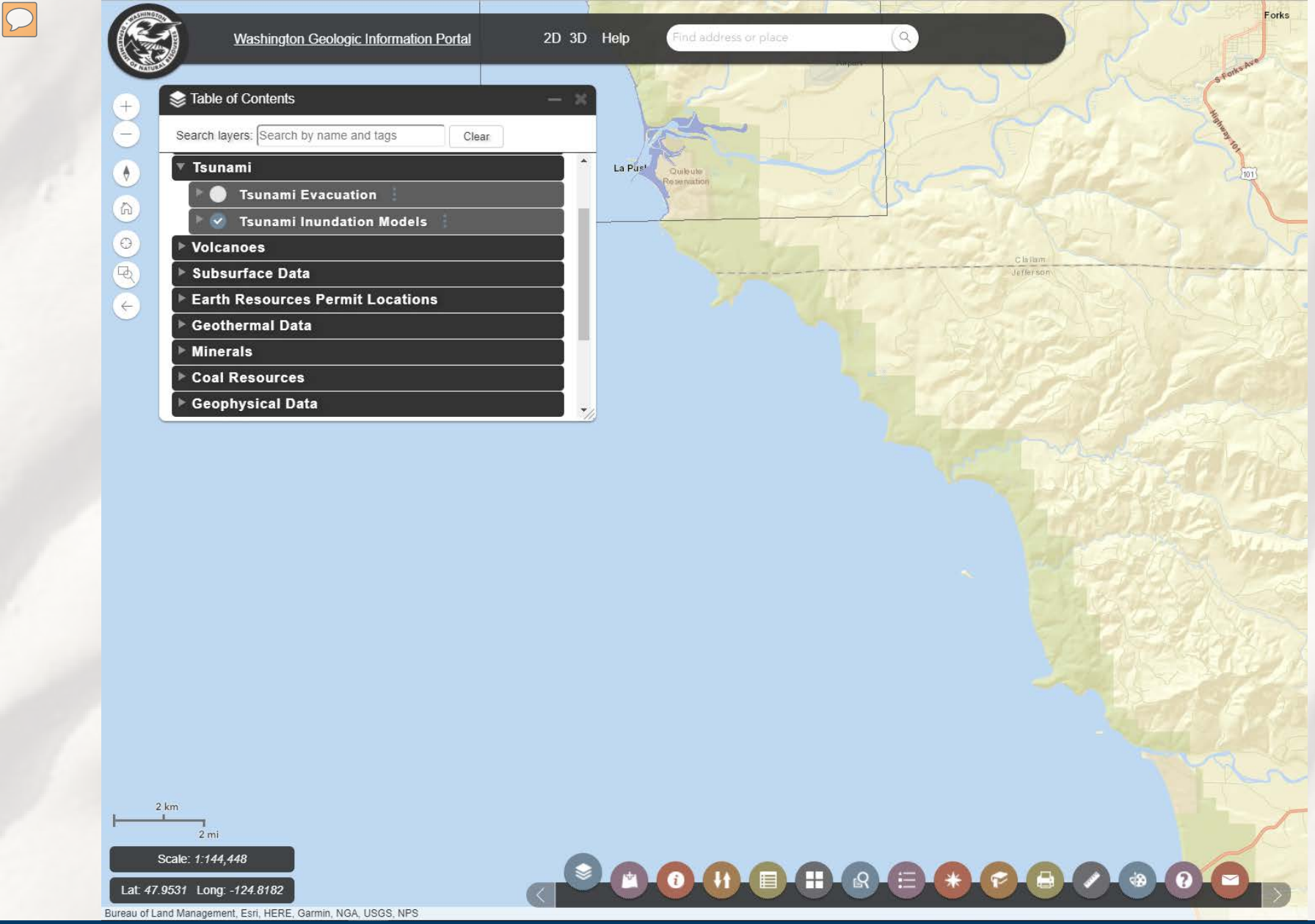
Ocean Shores
Montesano
Elma
Raymond
Ocean Park
Willapa National Wildlife Refuge
10 km
6 mi
Scale: 1:577,791
Lat: 47.2032 Long: -125.1231
Esri, HERE, Garmin, NGA, USGS, NPS | Washington State Department of Natural Resources Geology Division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Geophysical Data
Forks
S Forks Ave
Highway 101
101
La Push
Quileute Reservation
Clallam
Jefferson
2 km
2 mi
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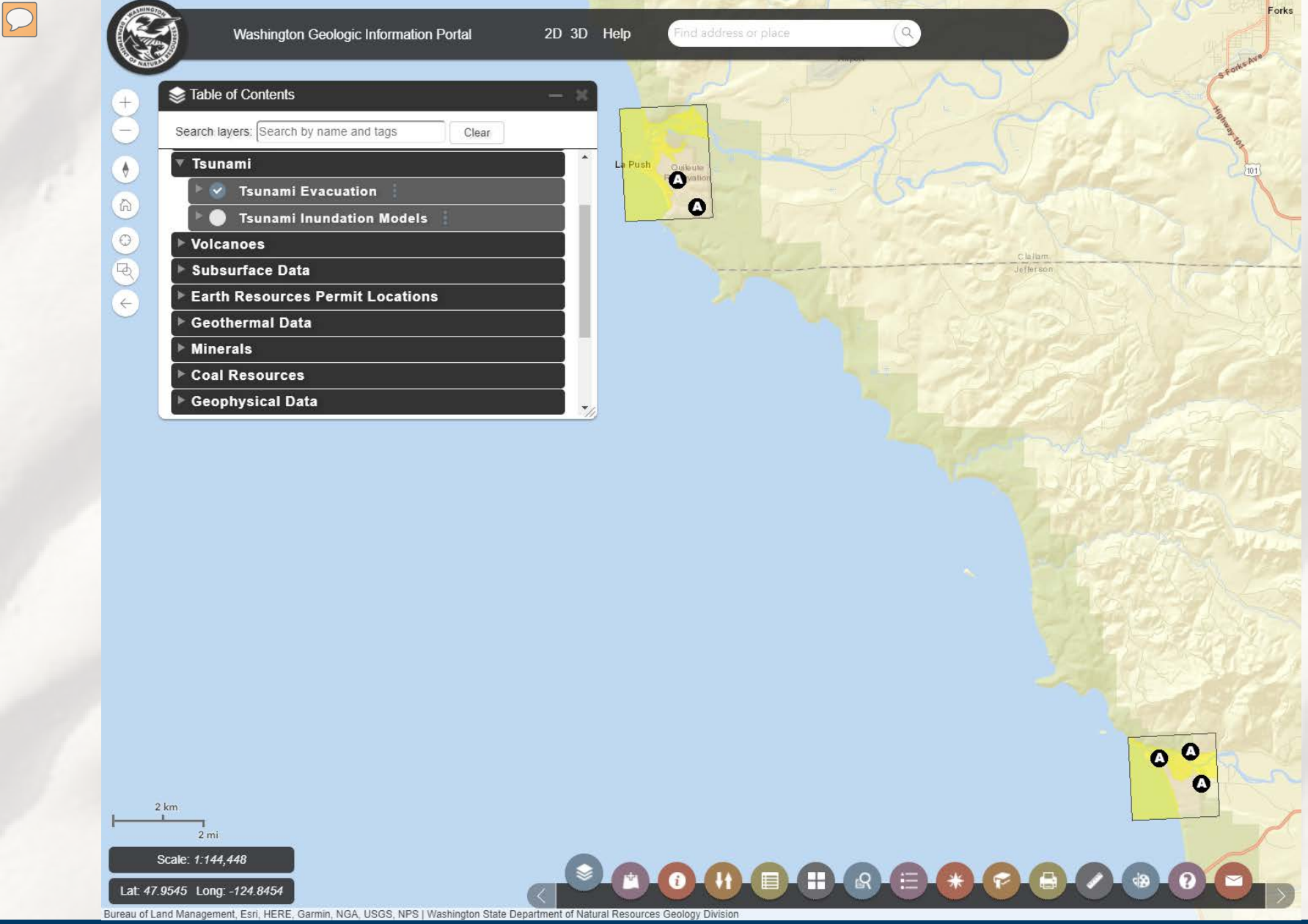
Bureau of Land Management, Esri, HERE, Garmin, NGA, USGS, NPS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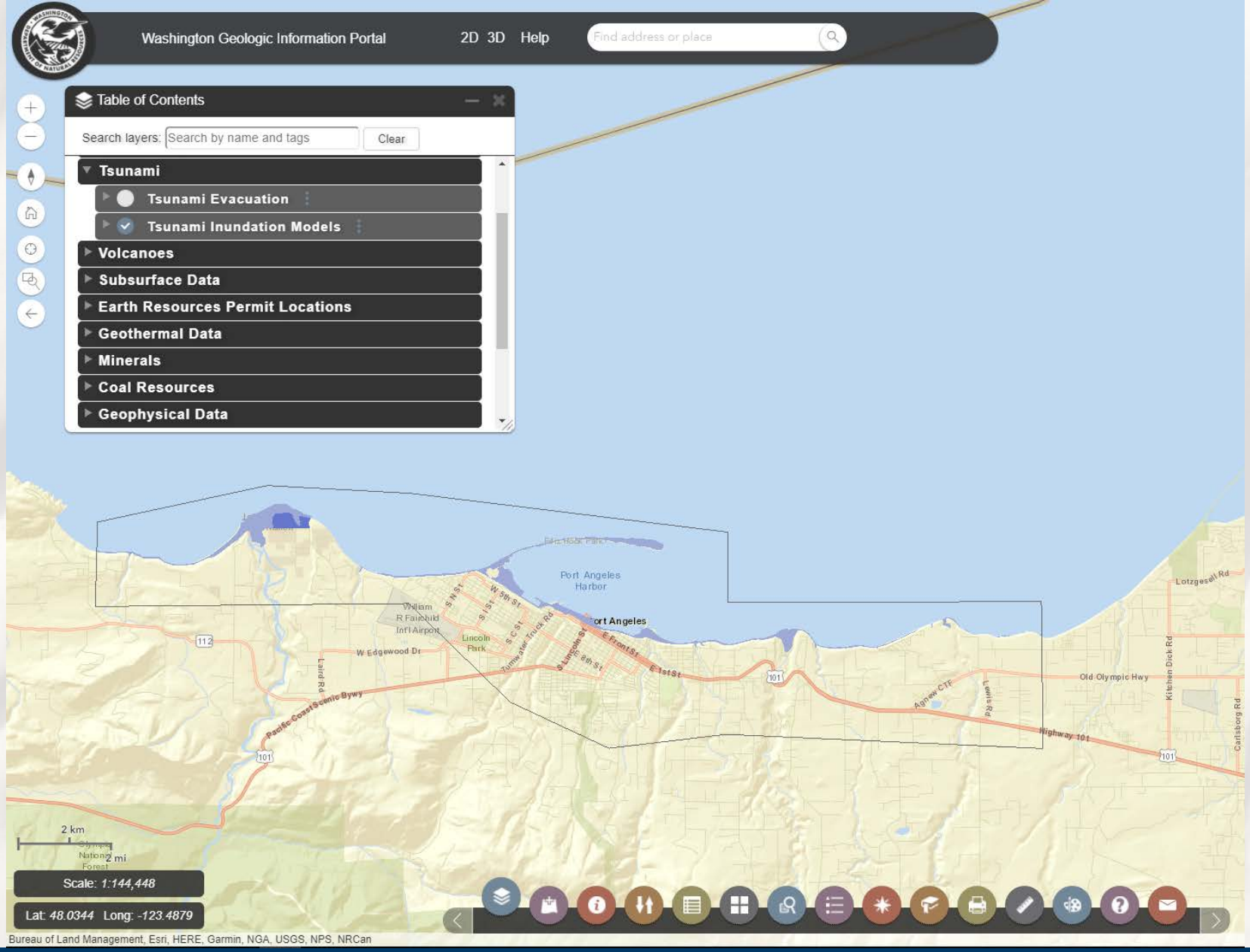
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Geophysical Data
Port Angeles Harbor
Port Angeles
William R Fairchild Int'l Airport
Lincoln Park
W Edgewood Dr
Laird Rd
Pacific Coast Scenic Bywy
Tumwater Truck Rd
S Lincoln St
E Front St
E 1st St
Old Olympic Hwy
Agnew CTF
Highway 101
Kitchen Dick Rd
Carlsborg Rd
Lotzgesel Rd
112
101
2 km
2 mi
Olympic National Forest
Scale: 1:144,448
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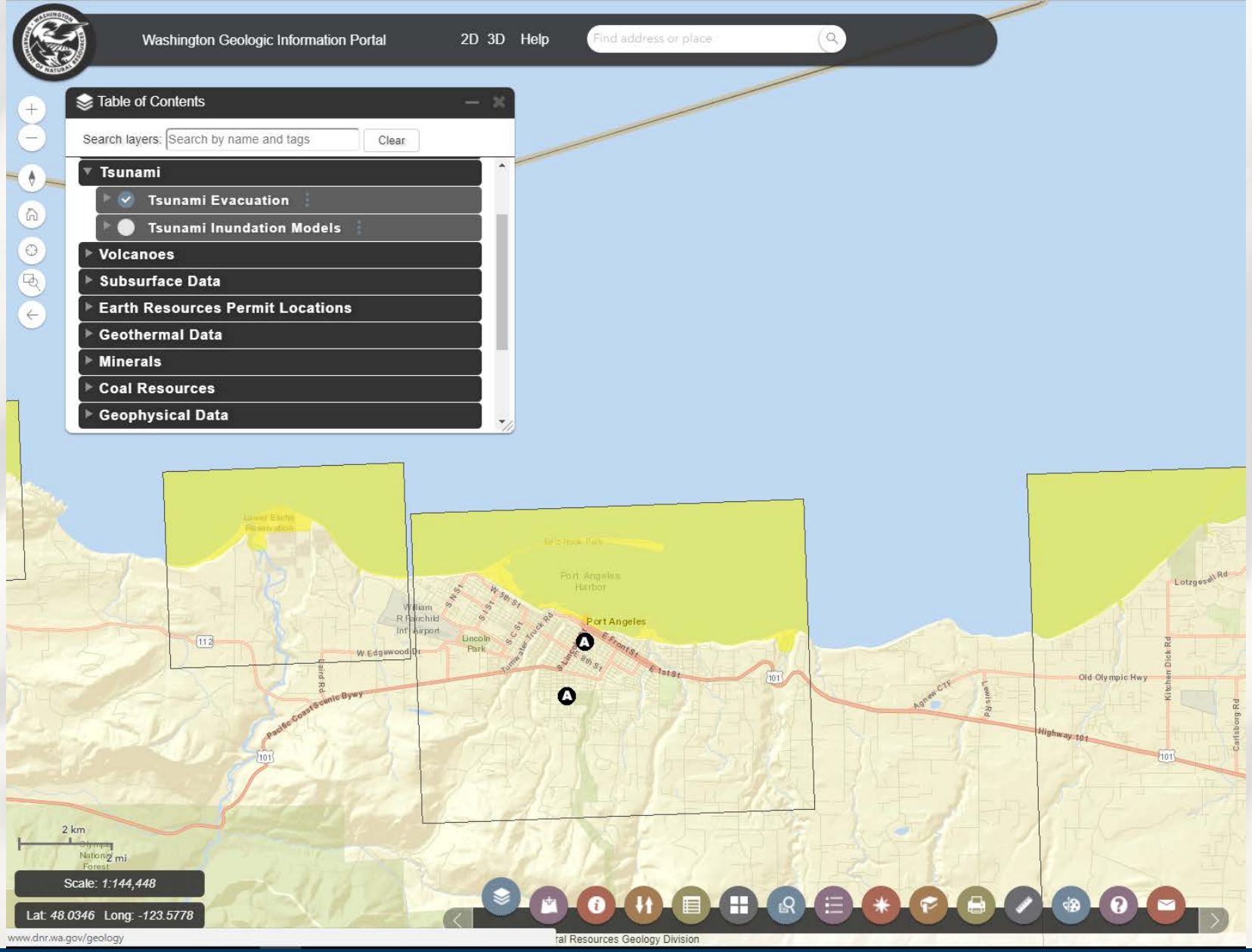
Bureau of Land Management, Esri, HERE, Garmin, NGA, USGS, NPS, NRCan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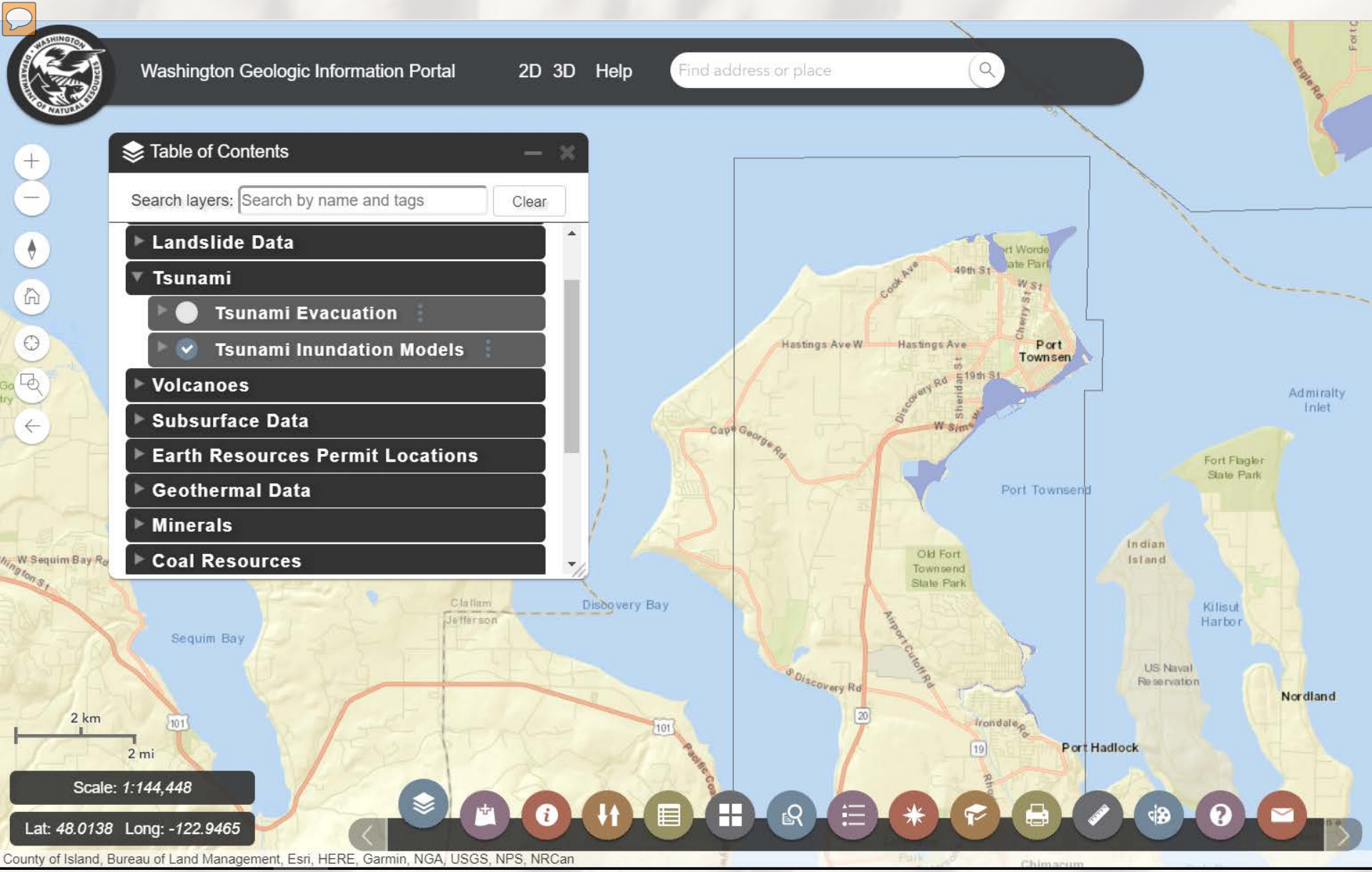
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Cook Ave
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19th St
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Discovery Rd
Sheridan St
Cherry St
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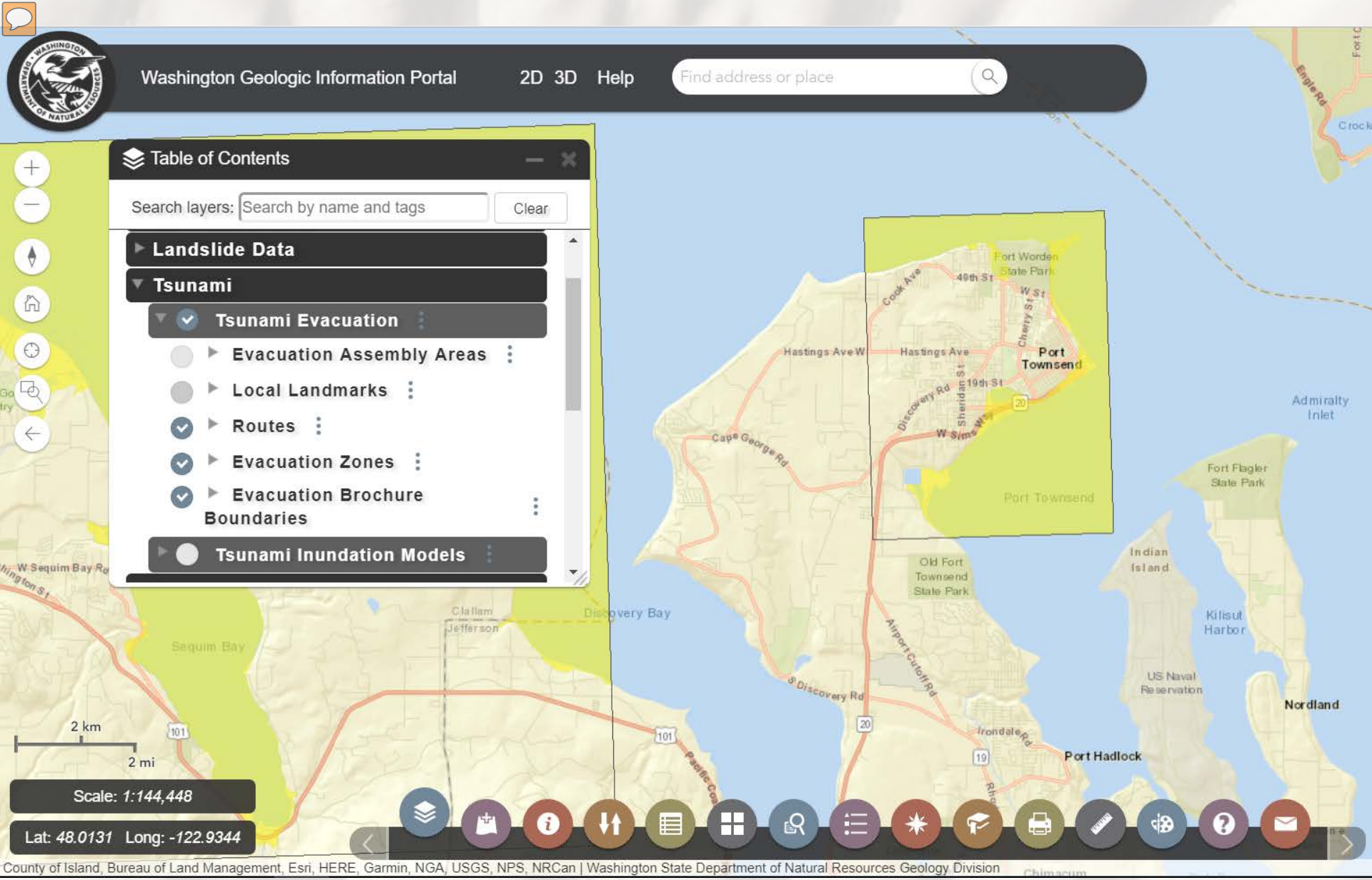
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S Discovery Rd
Irondale Rd
W Sequim Bay Rd
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Scale: 1:144,448
Lat: 48.0131 Long: -122.9344
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What is new (or coming soon)

2018–

Inundation maps and evacuation maps for Southwest Washington (Long Beach and Ocean Shores)

- Pedestrian walk map for Aberdeen/Hoquiam
- Inundation and pedestrian walk map for Anacortes-Bellingham vicinity
- Inundation and pedestrian walk map for Port Angeles and Port Townsend
- Hiring a new tsunami modeler!!!

2019–

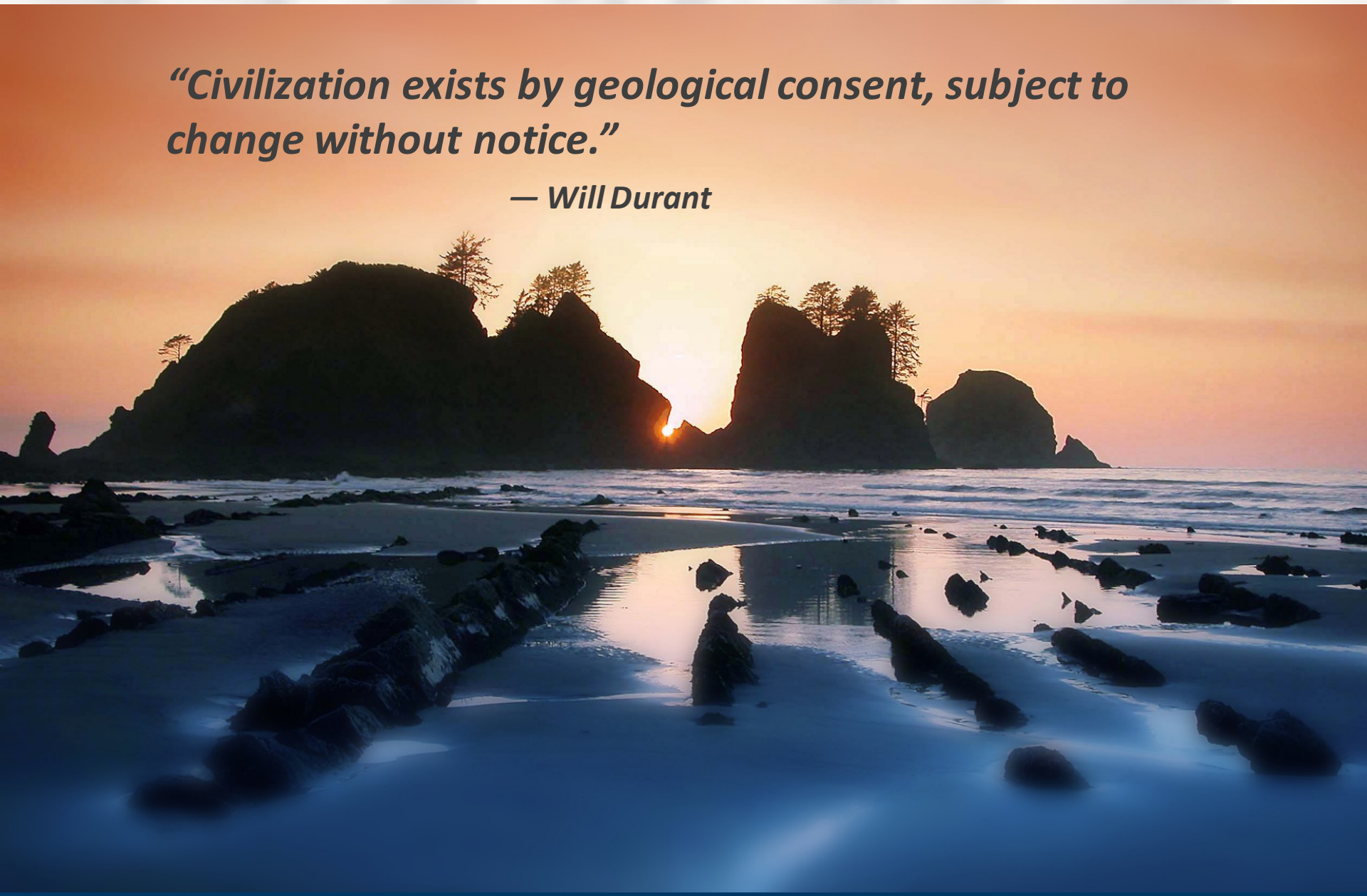
- Inundation modeling for remaining outer coast
- Create new and improved animations posted on our website

What is coming soon in tsunami science

- High resolution 3D models (site specific)
- State maritime guidance
- Sediment transport and debris tracking models (maritime focused)

"Civilization exists by geological consent, subject to change without notice."

— Will Durant



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