

SUB-SECTION 4G.4

PUYALLUP TRIBE ALL HAZARD MITIGATION PLAN TSUNAMI HAZARD

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Identification Description

Definition

Tsunami

The term tsunami itself is a Japanese word, meaning "large wave in harbor," and comes from the Japanese observation that such waves tend to be especially large and dangerous after they enter harbors. A tsunami, sometimes called a tidal wave, consists of a series of high-energy waves that radiate outward like pond ripples from the area in which the generating event occurred. They also build in height as they move into shallow water, just before striking the open shore or reaching the heads of bays, and then inundating the low-lying areas near the shore. Often, a quick recession of the water precedes the first wave crest.

Figure 4.4-1 Hawaii, 1957—Residents Explore Ocean Floor Before Tsunami¹



It is unusual for tsunamis to resemble the icon used to depict them, a towering wave with a breaking crest. While they can have that form it is more usual for them to resemble a series of quickly rising tides, or a surge of water. When they withdraw they do so with currents much like those of a river. Swift currents commonly cause much of the damage from tsunamis either from impacting objects directly or from the material picked up and transported along with the water,

such as logs, cars, or parts of buildings. They also pick up pollutants like oil, gas, sewage, etc. that can cause further damage as well as long term environmental problems.

Figure 4.4-2 Hawaii, 1949--Waves Overtake A Seawall²



Seiche

Seiches are water waves generated in enclosed or partly enclosed bodies of water such as reservoirs, lakes, bays and rivers by the passage of seismic waves (ground shaking) caused by earthquakes. Sedimentary basins beneath the body of water can amplify a seismic seiche. Seismic waves also can amplify water waves by exciting the natural sloshing action in a body of water or focusing water waves onto a section of shoreline.³

Types⁴

Tsunamis are a secondary hazard, the result of geological events. Typically tsunami and seiches are triggered by earthquakes and landslides, see Earthquake and Landslide Hazard Chapters of this plan. These sources are discussed below.

Earthquake Source

Sudden raising or lowering of a portion of the Earth's crust during earthquakes generally causes a tsunami, although landslides and underwater volcanic eruptions can generate them as well. Movements of the sea floor or lakebed, or rock fall into an enclosed body of water, displace the water column, setting off a series of waves that radiate outward like pond ripples.

Landslide Source

Three distinct landslide situations could result in a significant tsunami affecting local communities bordering Puget Sound: submarine landslides on delta fronts, submarine slides elsewhere in the Sound, and slides from adjacent uplands. These slides can be induced by earthquakes.

Subaerial Landslides⁵

The two major geological parameters that control the generation of a water wave from subaerial landslides are the volume of the slide mass, and the motion of the mass as it reaches the water body. Some very large prehistoric landslides have been mapped along Puget Sound bluffs; when reactivated, these deep-seated landslides tend to be very slow moving (inches per day), and would not appear to be capable of generating a tsunami.

Subaerial landslides that fall into Puget Sound with sufficient volume and velocity, and at the appropriate tidal conditions, can generate large water waves.

River Delta Failures

Submarine landslides can originate on the delta slopes of major rivers flowing into the Sound, in particular the Nisqually, Puyallup, Duwamish, and Snohomish rivers.

Non-Deltaic Submarine Landslides

Additional landslides originate on steep submarine slopes that are not part of a delta. Away from deltas, submarine areas most susceptible to landsliding may be in the vicinity of faults having Quaternary displacement.

Profile

Location and Extent

In Washington State, the Pacific Coast, Strait of Juan de Fuca, and Puget Sound are all at risk from tsunamis. In addition, large lakes and other enclosed bodies of water, like Puget Sound south of the Tacoma Narrows, could be affected by a seiche. Tsunamis generated off the Washington Coast will have very little energy left after traveling down the Strait of Juan de Fuca and changing direction to the south at Admiralty Inlet and are not expected to cause much if any damage within Pierce County.

Tsunamis generated within Puget Sound and seiches on the lakes and southern portions of the Sound directly and indirectly affect the Planning Area, specifically the Commencement Bay area. Future Coastal Velocity Zone Maps will show the tsunamis and seiche hazard location and extent for the County. Preliminary research is shown on Figure 4.4-5 Tsunami Inundation and Current-Based on Earthquake Scenario. Projected increases in sea level due to climate change combined with subsidence in portions of Puget Sound will exacerbate these problems.

Earthquake Source

Earthquake induced tsunamis can occur throughout the Puget Sound and within the Planning Area, especially with the Tacoma Fault's proximity, see Figure 4.4-3. Any tsunami located within Pierce County could affect the coastal regions of the Planning Area. See Figure 4.4-3 for a schematic of fault zone locations in the Puget Sound region, with vertical deformation contours for an M_w 7.3 Seattle Fault. The figure also illustrates the vertical deformation for an M 9.1 Cascadia earthquake, and Pacific Northwest peak ground acceleration with 2% probability of exceedance in 50 years.

Figure 4.4-3 Puget Sound Fault Zone Locations, Vertical Deformations, and Peak Ground Acceleration⁶

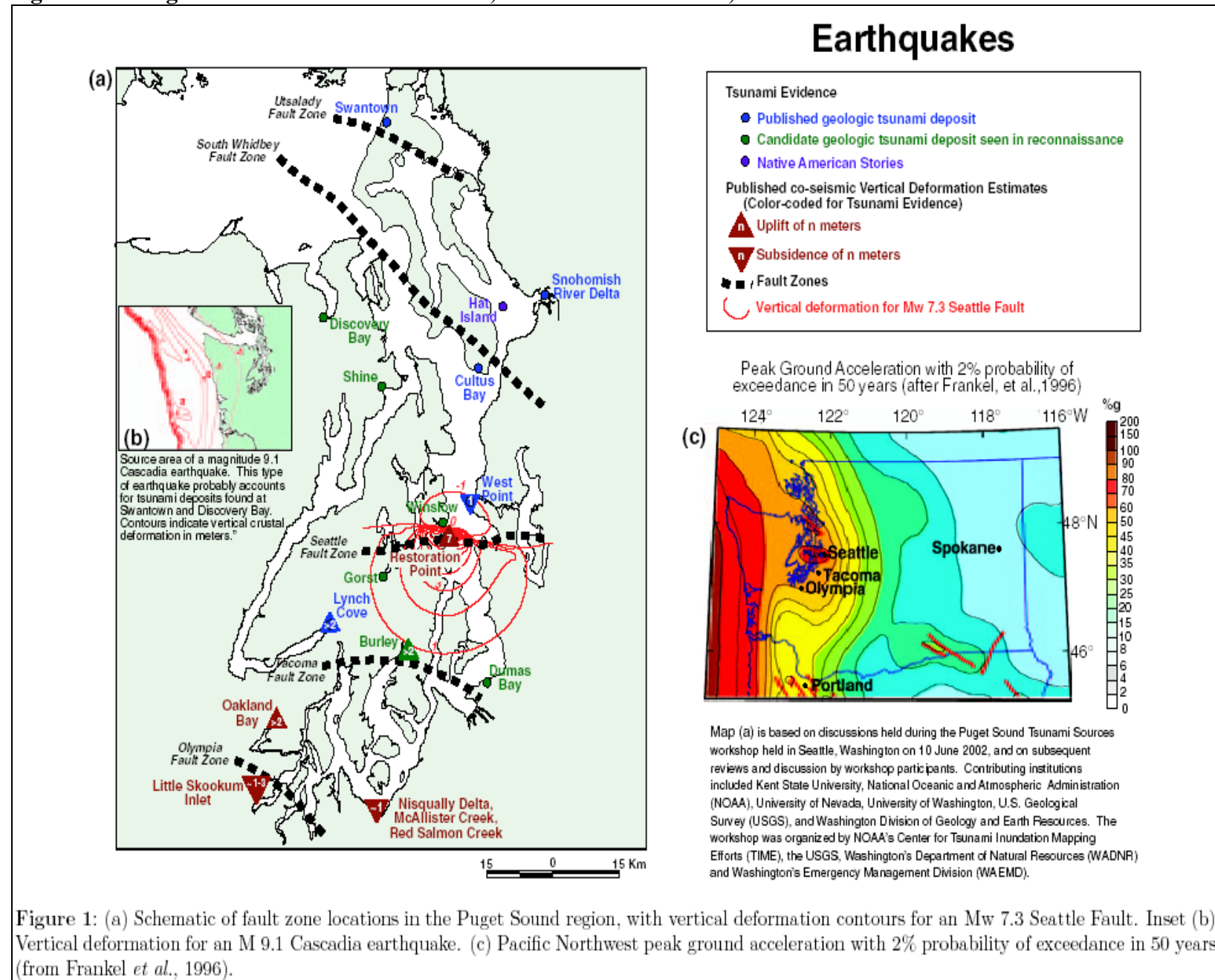


Figure 1: (a) Schematic of fault zone locations in the Puget Sound region, with vertical deformation contours for an Mw 7.3 Seattle Fault. Inset (b) Vertical deformation for an M 9.1 Cascadia earthquake. (c) Pacific Northwest peak ground acceleration with 2% probability of exceedance in 50 years (from Frankel *et al.*, 1996).

A more detailed rendition of the Tacoma and Seattle Faults is shown in Map 4.4-1. In addition, this shows those areas that have a history of uplift and subsidence in previous earthquake events, probably leading to tsunami generation. Displacement along both the Tacoma and Seattle faults happened approximately 1,100 years ago.⁷

Map 4.4-1 Seattle and Tacoma Faults⁸

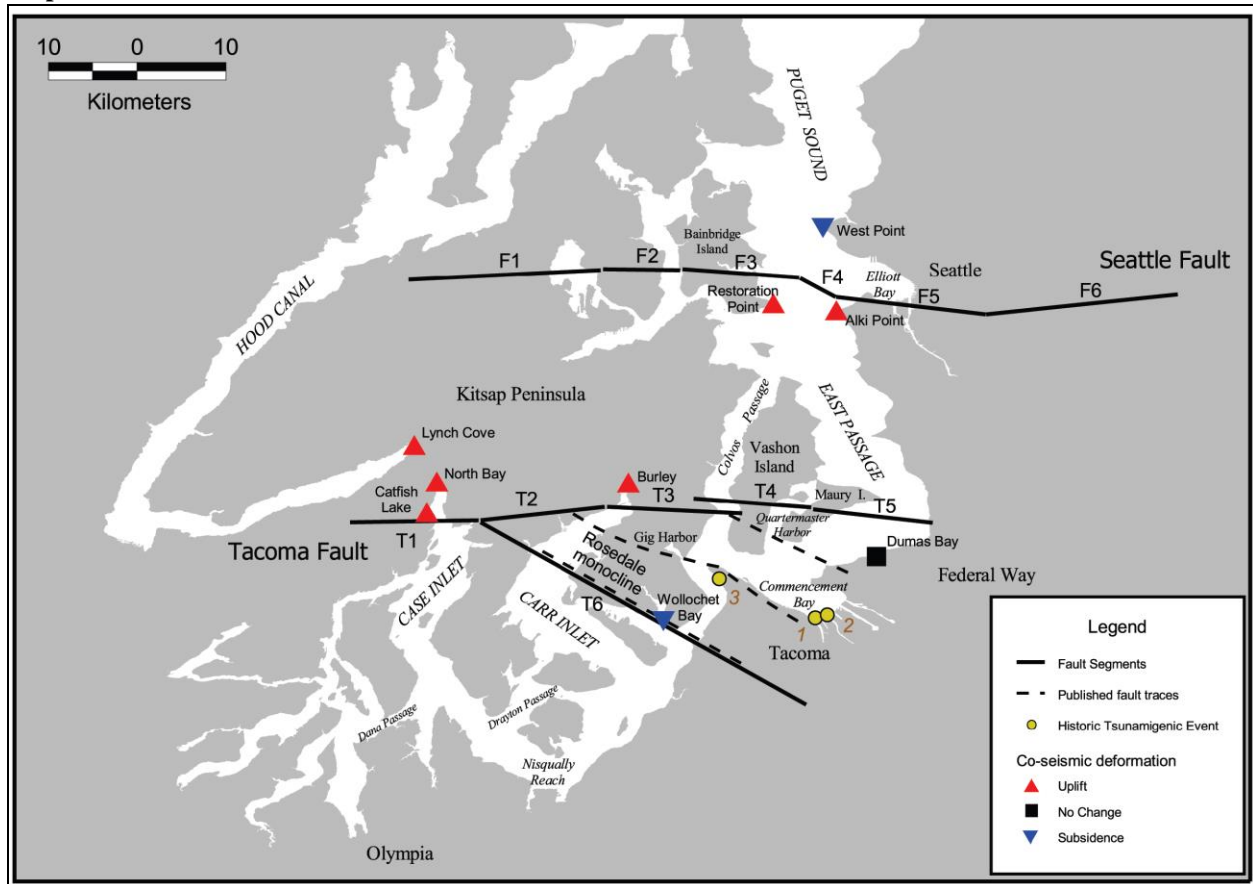
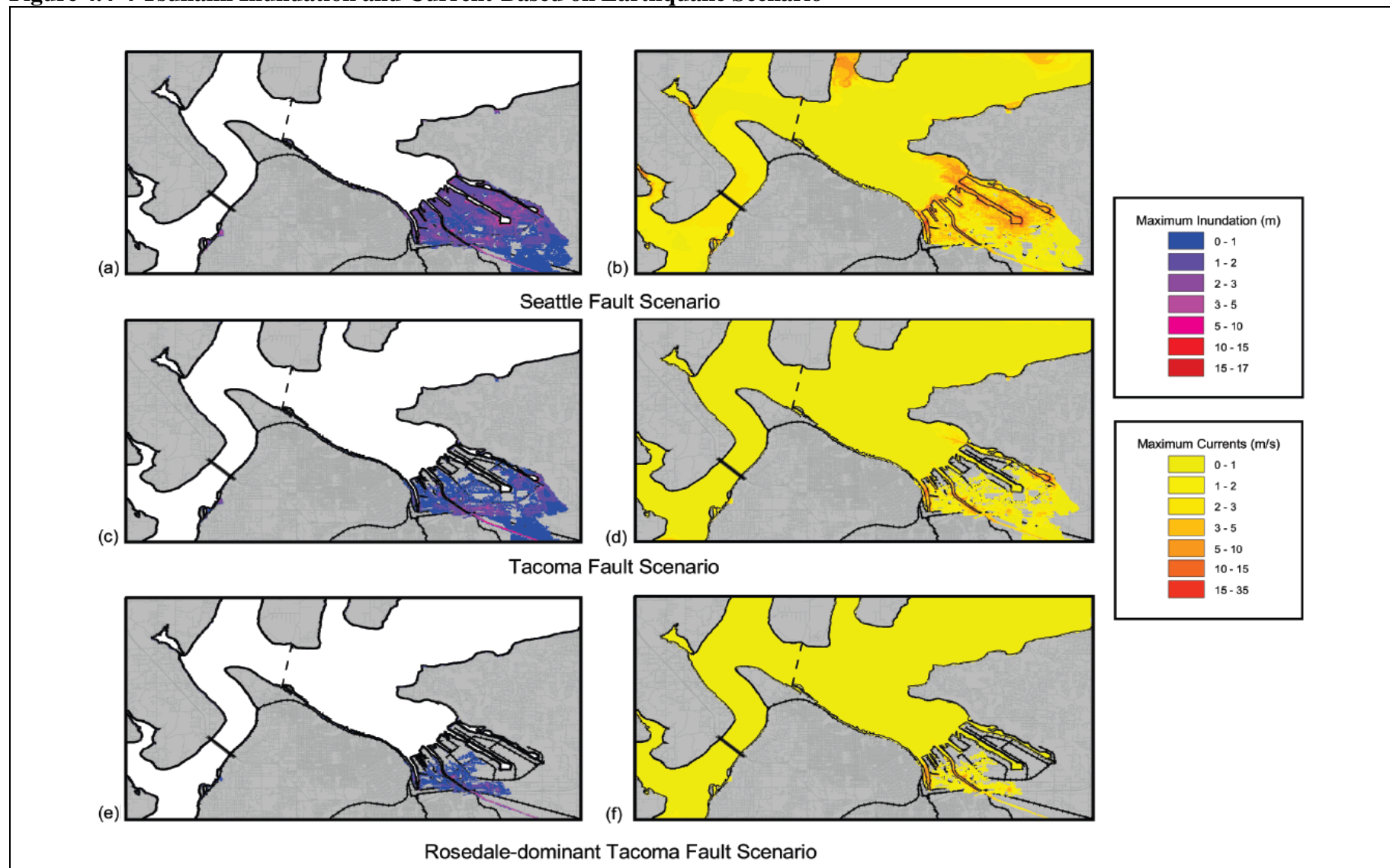


Figure 4.4-4 identifies the maximum inundation (a, c, e) and maximum wave speeds (b, d, f) for each earthquake source scenario. Most inundation occurs within low-lying, relatively flat regions of the study area such as the Port of Tacoma harbor in Commencement Bay. Minimal inundation occurs along steep topographical slopes. Consequently, the inundation is determined primarily by local topography rather than offshore wave dynamics.

The Seattle Fault scenario creates the most inundation and highest currents within the study area due to the large displacement of water in the deepest and widest region of Puget Sound. The Tacoma Fault scenario has significant inundation in the Port of Tacoma region, but with smaller amplitudes. This scenario causes less inundation overall since much less water is displaced in the narrower and shallower regions of Carr Inlet, Colvos Passage, and East Passage. The Rosedale-dominant Tacoma Fault scenario causes the least inundation and lowest current speeds due to relatively small displacements in the regional channels.⁹

Figure 4.4-4 Tsunami Inundation and Current-Based on Earthquake Scenario¹⁰



Earthquakes could also lead to landslide-induced tsunamis, the location and extent of which are described below.

Landslide Source

Subaerial landslides can occur on most bluffs of the coastal regions of the Planning Area, specifically Commencement Bay. Delta failure landslides can originate on the delta slopes of major rivers flowing into the Sound, in particular the Puyallup River delta leading into Commencement Bay. Either of these instances can induce a tsunami.

The following two figures, Figures 4.4-5 and 4.4-6, show some of the subaerial and deltaic landslide history and potential for future slides tsunami that would impact coastal areas within the Planning Area.

Figure 4.4-5 shows potential landslide zones, including the location of the 1949 Tacoma Narrows slide and unpublished field data for large submarine slides. Also presented are contours of peak ground acceleration with two percent probability of exceedance in 50 years, locations for which evidence of past tsunamis exists, and a TIME Center analysis of gridded bathymetric and topographic data to identify sites with steep coastal topography adjacent to deep coastal water.

Figure 4.4-6 shows the major river deltas in Puget Sound, the probabilistic shaking hazard contours, and notes areas where past delta failures have occurred. Deltas of the Puyallup, Duwamish, and Snohomish Rivers probably pose more of a landslide hazard than do other Puget Sound deltas, as shown by historical submarine landslides on the Puyallup River delta, the proximity of these three deltas to major port facilities, and stability analysis of the Duwamish River delta slope.

Figure 4.4-5 Puget Sound Landslide Areas and Corresponding Tsunamis¹¹

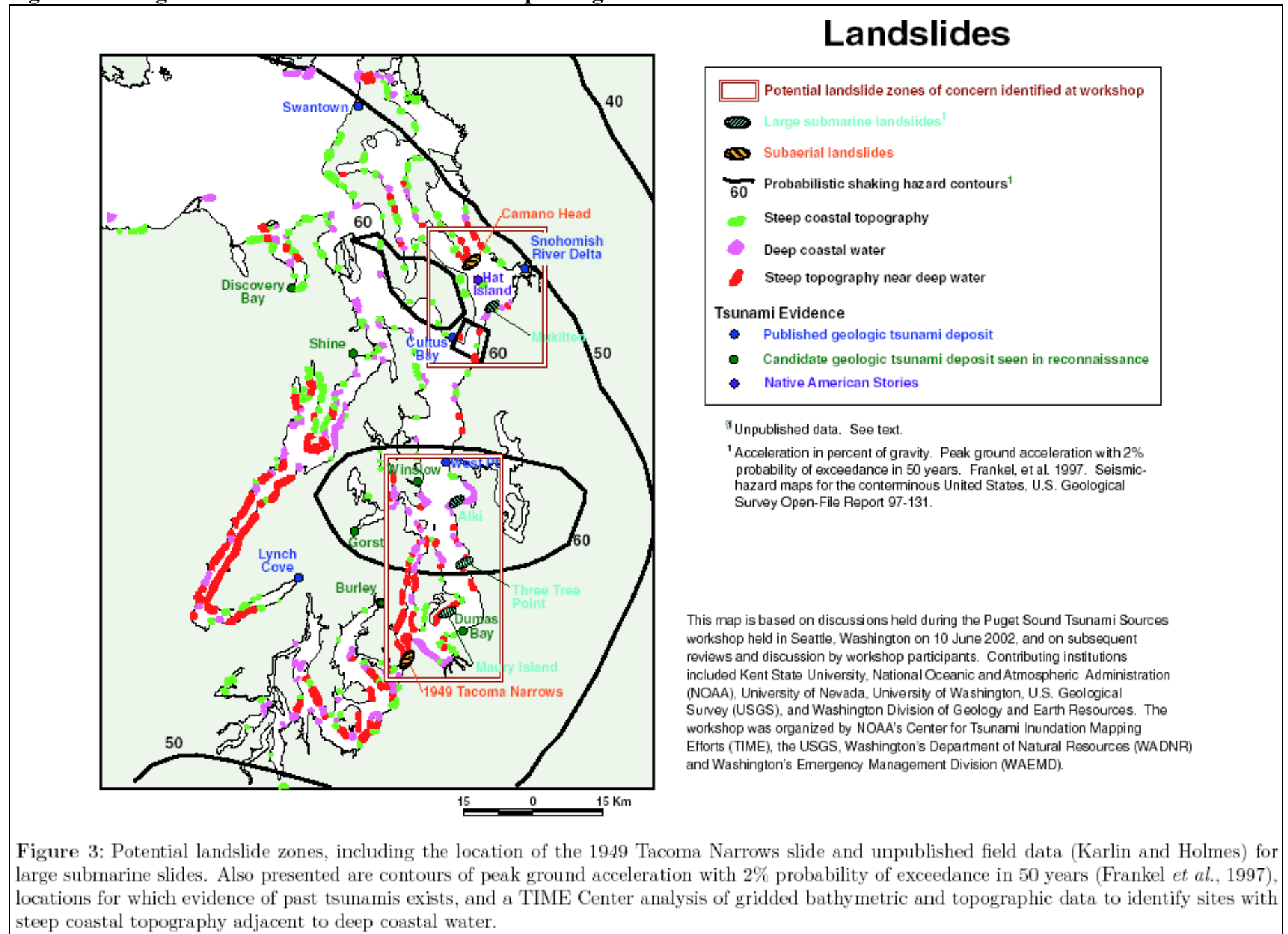
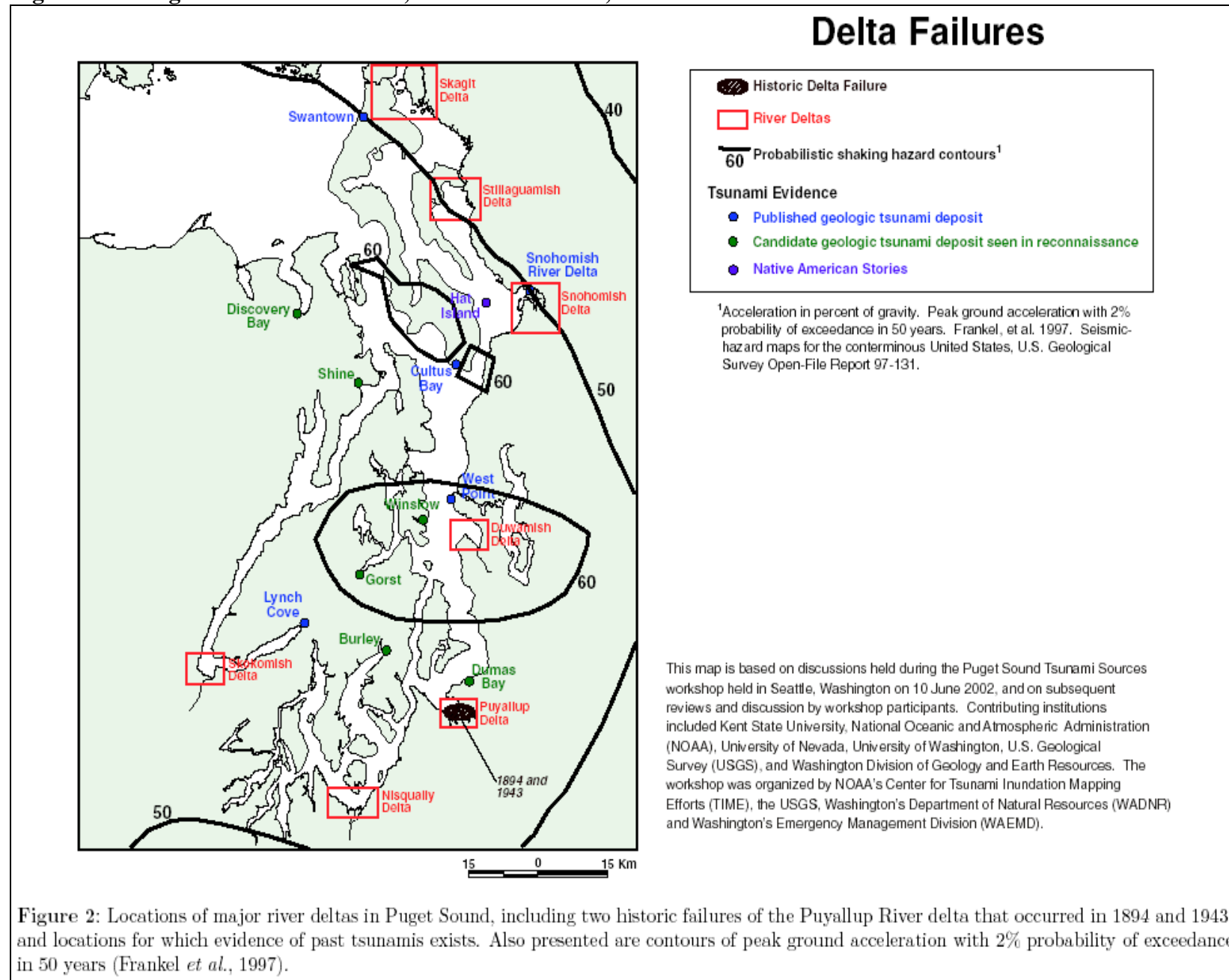


Figure 4.4-6 Puget Sound River Deltas, Tsunami Evidence, and Peak Ground Acceleration¹²



Occurrences

The recorded history of tsunamis is short and research is currently being conducted to develop a chronicle of past occurrences of tsunamis in Puget Sound. Below is a descriptive narrative of each occurrence organized by the tsunami's source.¹³

Earthquake Source

Although few earthquakes result in tsunamis at Puget Sound, each of the three earthquake sources has demonstrated its capability of generating such waves. A landslide that set off a tsunami in Tacoma Narrows occurred a few days after the 1949 earthquake in the Juan de Fuca plate. The earthquake of ca. A.D. 900 on the Seattle fault caused uplift that triggered a tsunami in central Puget Sound that, because of the geography of the Sound waterways, may have reached the Planning Area. The Seattle fault quake also caused landslide-generated waves in Lake Washington. Tsunamis from plate-boundary earthquakes probably account for several sand sheets on northwestern Whidbey Island and at Discovery Bay.

Figure 4.4-3 illustrates vertical deformation from a hypothetical 7.3 Seattle Fault event and a 9.1 Cascadia Subduction Zone event. Figures 4.4-8 and 4.4-9 illustrate the visible scarp on the floor of the Puyallup River delta.

It is possible that other cross Sound earthquake sources could also generate a tsunami. However at this time there has not been much study done on the areas affected by these potential waves. Other potential sources that could generate a tsunami that would affect the Planning Area include the South Whidbey Fault, the Utsalady Fault and the fault underlying Olympia.

Landslide Source

Subaerial Landslides

A tsunami was generated by a landslide at the Tacoma Narrows that occurred three days after the 1949 Ms 7.1 Olympia earthquake (see Figure 4.4-7). The 1949 tsunami was caused by a landslide on the north end of Salmon Beach, Tacoma. A 400ft high cliff gave way and slid into the Puget Sound. Water receded 20-25 feet from the normal tideline, and an 8 foot wave rushed back against the beach, smashing boats, docks, a wooden boardwalk, and other waterfront installations in the Salmon Beach area.¹⁴ It moved both directions within The Narrows causing damage at Salmon Beach, Gig Harbor, and as far south as Day Island. Shortly after the earthquake geologists had noticed that cracks had formed at the top of the slope and had notified residents that a slide was possible. Many people evacuated their property and while the slide itself did not damage the homes there was damage from the tsunami itself.

Native American oral tradition suggests that in 1825, a large subaerial landslide at Camano Head, in Island County at the extreme south end of Camano Island, created a water wave that drowned many people on Hat Island. Because the story does not include ground shaking, this landslide was not necessarily associated with an earthquake.

Figure 4.4-7 Salmon Beach, Pierce County, 1949—Tsunamigenic Subaerial Landslide¹⁵



Delta Failure Landslides

In 1894, a large submarine landslide occurred at night on the Puyallup River delta in Commencement Bay; see Figure 4.4-10, resulting in two fatalities and the destruction of 300 feet of the Northern Pacific freight docks and other port facilities. It also created at least a ten-foot wave in the Old Town section of Tacoma, which washed over homes on the tide flats. A smaller submarine landslide in 1943 destroyed jetties along the mouth of the Puyallup River.¹⁶ There is also evidence of other slides in the same area in 1989, but that slide did not generate a wave that was noticeable in Commencement Bay. (See Figure 4.4-9 for locations of unpublished field data for large submarine slides.)

Because of the relatively brief historical record of tsunamis in Puget Sound, it is important to examine similar tsunamis occurring elsewhere, as their characteristics help to determine vulnerability here in Puget Sound (for more analysis, see the vulnerability section). In addition to the Puget Sound examples, larger submarine landslides have occurred on river deltas in British Columbia and Alaska. Some of these slides were triggered by large earthquakes, and others resulted simply from river delta evolution, including over-steepening of the delta front.

Known historical Puget Sound river delta failures have all been far smaller than these Alaskan examples. Figure 4.4-6 shows locations of major river deltas in Puget Sound, including two historic failures of the Puyallup River delta that occurred in 1894 and 1943, and locations for

which evidence of past tsunamis exists. Figure 4.4-8¹⁷ and 4.4-9 and their accompanying descriptions illustrate previous submarine landslides on the Puyallup River delta.

Non-Deltaic Submarine Landslides

Unpublished seismic profiling data and mapping indicate that large submarine landslides have occurred on submarine slopes in Puget Sound, Lake Washington, and Lake Sammamish that are not associated with large river deltas, but that appear proximal to a number of Quaternary faults that cross the Sound.¹⁸

Future Puget Sound tsunamis are guaranteed by a combination of setting and history. The inland waters and lakes of the Puget Sound lowland cross active faults and contain records of earthquakes and landslides. From geologic and historical evidence, it is known that some of these events have generated tsunamis.¹⁹

The Planning Team determined the probability of recurrence for the tsunami hazard in the Planning Area to be an “unknown but anticipated occurrence.” This is based on information from past severe storms occurrences, information from local hazard experts. Probability of recurrence is discussed in further detail in the vulnerability section below (see worst-case scenario portion).

Recurrence Rate

Tsunamis have been a part of Pierce County long before there was a written record of their existence. Data from field studies shows that both the Seattle and Tacoma faults that run under Puget Sound had displacement around 1,100 years ago.²⁰ These would have resulted in tsunamis impacting the coastal areas of the County. Recent locally generated tsunamis from the various sources mentioned above, two submarine and one subaerial, have impacted Pierce County three times in the last 120 years. The last of these was 65 years ago. This does not mean that Pierce County is overdue for another one. It does however point to the erratic nature both of the cause and the recurrence interval. There were earthquake generated tsunamis (1,100 years ago) as well as ones from landslides into Puget Sound (1949) and those from underwater landslides (1894 and 1943). There is too short of a historic record to give a definitive answer for a recurrence rate. Taking these into consideration, until further research can provide a better estimate a tentative recurrence rate of plus or minus 100 years will be used.

Figure 4.4-8 Puyallup River Delta—Submarine Landslides

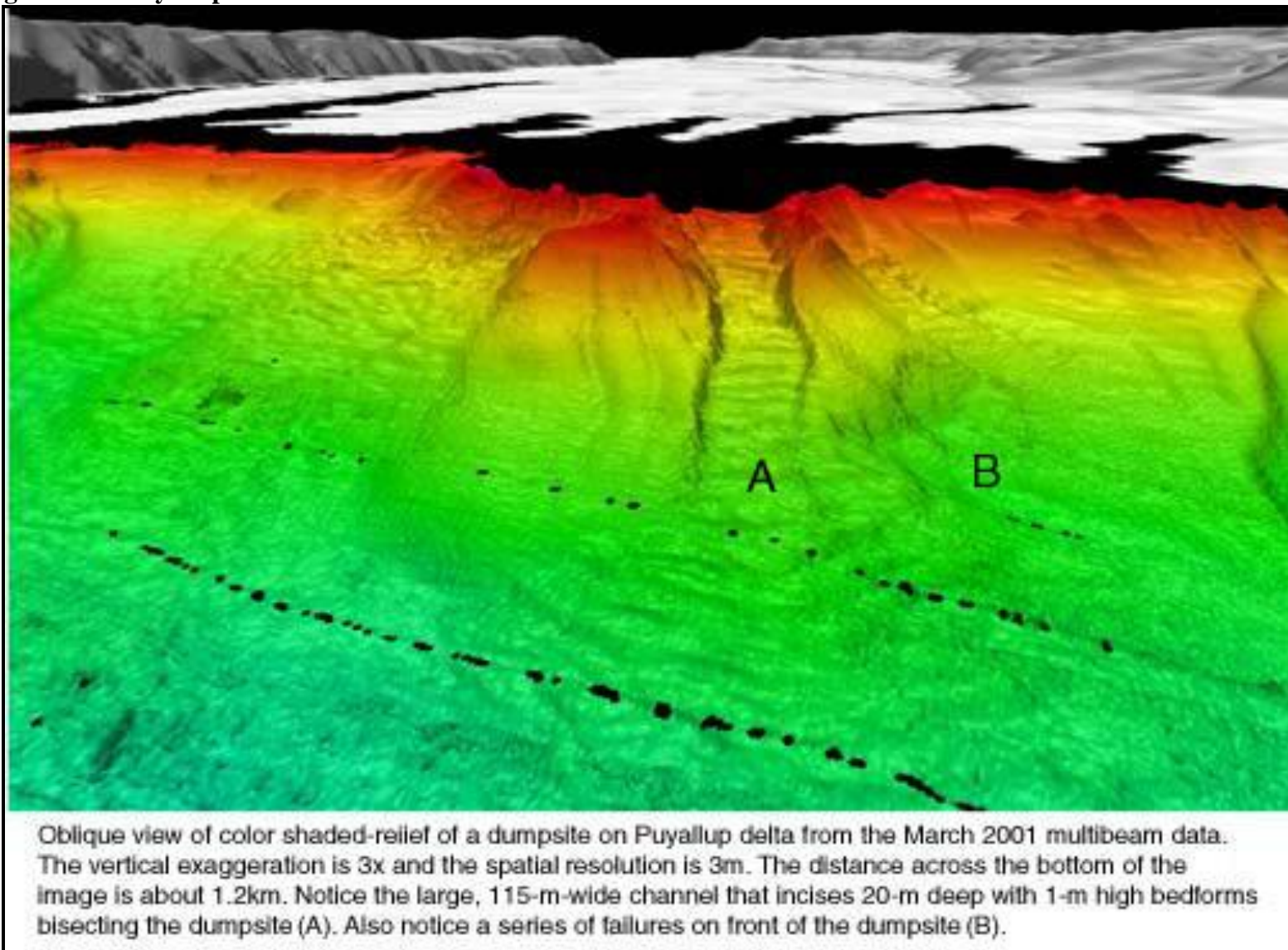


Figure 4.4-9 Puyallup River Delta—Submarine Landslides and Scarp

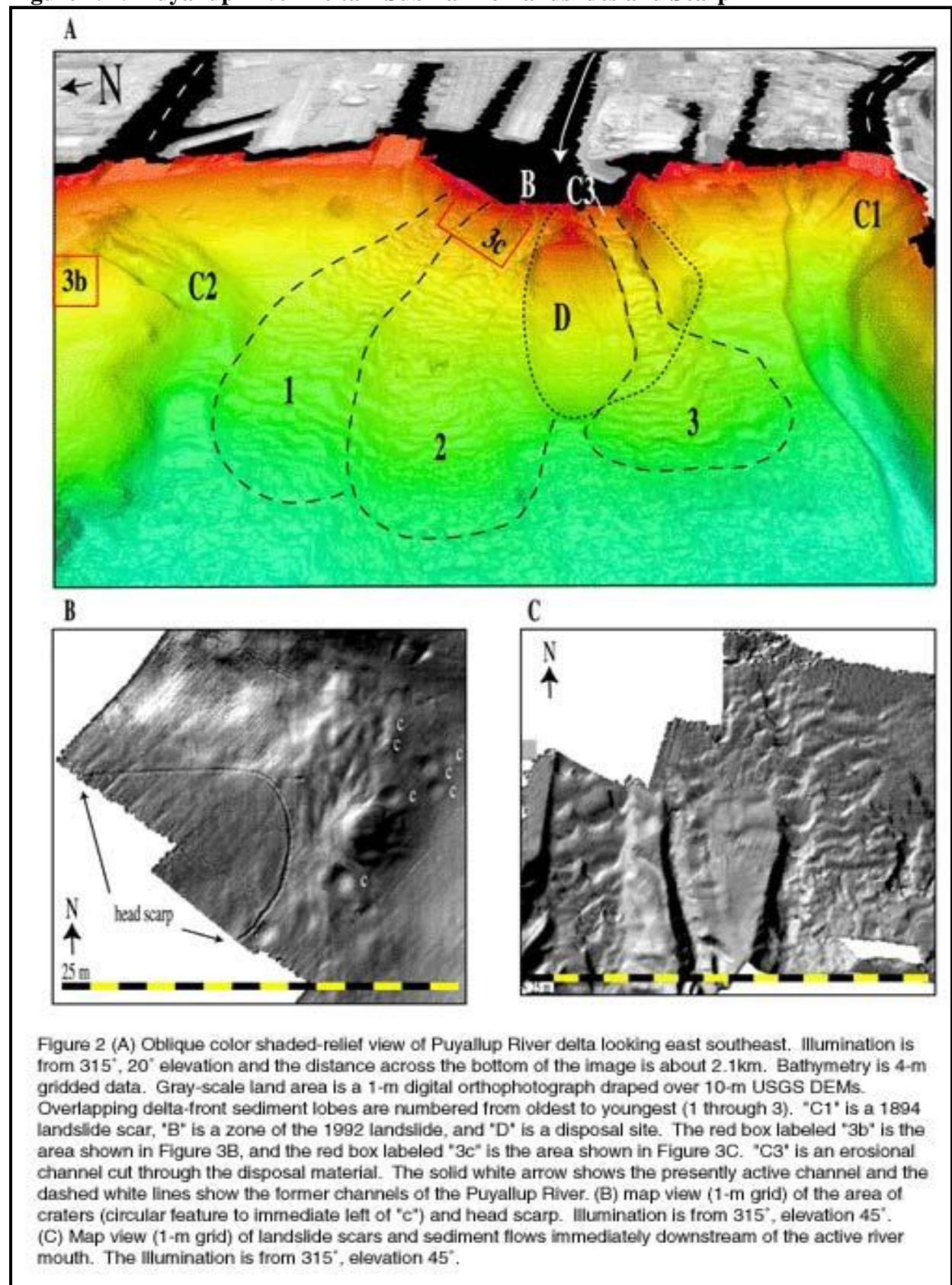


Figure 4.4-10 Damage in Tacoma from the 1894 Tsunami²¹



Vulnerability

Because of its vulnerability to the earthquake and landslide hazards, coastal regions of Puget Sound are consequently vulnerable to tsunamis generated by local crustal earthquakes or by surface and submarine landslides (both deltaic and non-deltaic). Map 4.4-2 illustrates those areas in Washington State that are vulnerable to the tsunami hazard. The map shows that the Planning Area is a vulnerable region (see Tacoma-area outline).

Tsunamis travel rapidly in Puget Sound, reaching speed of 70-120 mi/hr in the deeper channels. They can traverse the length of Puget Sound's main basin in 30 minutes and can propagate across many of its channels in a minute or less.²²

The sequence of tsunami waves may arrive at the shore over an extended period of time. The second wave will follow the first within a few minutes to an hour later; and the first wave may not be the maximum wave. The duration of a tsunami wave train within Puget Sound will be a few hours, and its wave heights will depend on the state of the tide. A rapid fall of the tide from high to low water can trigger shoreline landslides that in turn can generate tsunamis. If a tsunami were to occur off the mouth of the Puyallup River during high tide, it could travel up the river for some distance.

Tsunamis typically cause the most severe damage and casualties near their source. There, waves are highest because they have not yet lost much energy. Damage from tsunamis in south Puget Sound would be isolated to sea-level, on-shore, and near-shore populations. The nearby coastal population often has little time to react before the tsunami arrives. Persons caught in the path of a tsunami often have little chance to survive; debris

may crush them, or they may drown. Children and the elderly are particularly at risk, as they have less mobility, strength, and endurance.

Floating debris like logs, boats, or shoreline houses may be picked up and may batter coastal installations, other boats, and ships. Moored ships may be swamped and sunk, or be left battered and stranded high on the shore. In many instances the damage done to them results from striking the bottom of the area they are moored to when the water runs out. Breakwaters and piers may collapse, sometimes because of impact of waves. Railroad yards and oil tank farms situated near the waterfront are particularly vulnerable and could lead to potential hazardous materials incidents. Gas, oil and other hazardous materials may leak into the water from damaged boats. This could lead to long-term environmental damage.

Fires may be started due to damage to either boats or industrial facilities. Port facilities, fishing fleets, and public utilities are frequently the backbone of the economy of the affected areas, and these are the very resources that generally receive the most severe damage from tsunamis. Until debris is cleared, wharves and piers rebuilt, utilities restored, and the fishing fleets reconstituted, communities may find themselves without fuel, food, and employment. Wherever water transport is a vital means of supply, disruption of coastal systems can have far reaching economic effects.²³

In the Planning Area, the area's most vulnerable to the tsunami hazard are the developed areas on shorelines, in low-lying areas, near tidal flats, or those near the mouth of the Puyallup River.²⁴

Below is a discussion of the local factors that contribute to the Planning Area's vulnerability to the tsunami hazard organized by source.

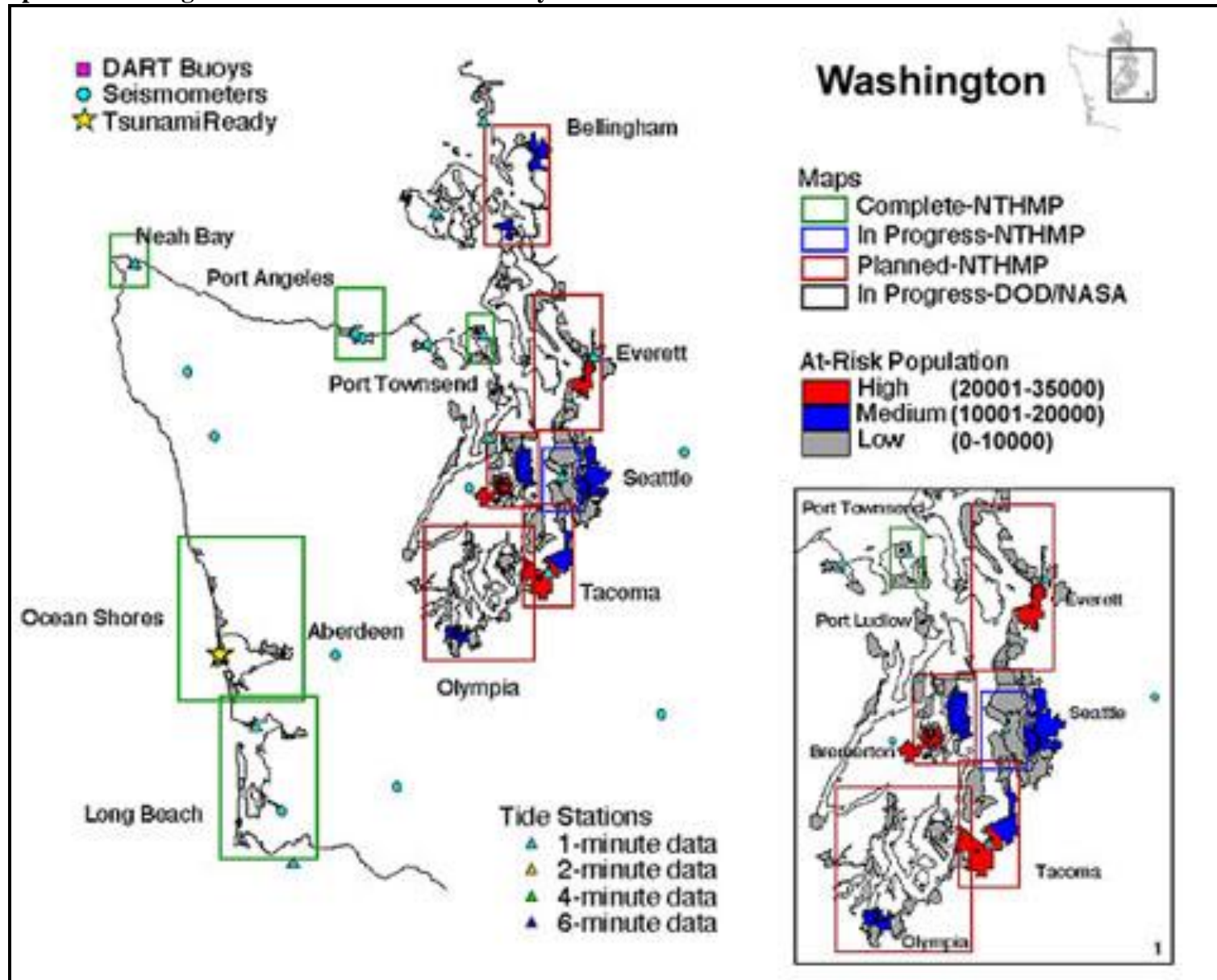
Earthquakes Sources

Trans-Pacific or outer coastal tsunamis should not affect the inland waters of the Planning Area. Due to the configuration of the Sound, and the Planning Area's distance from the coast, the energy would be largely dissipated before reaching the Area. Tsunamis in the Planning Area can, however be generated by large crustal earthquakes on faults. Because of its proximity, the Planning Area may be vulnerable to tsunamis generated on the Seattle Fault, see Map 4.4-3. The portion of the Tacoma Fault that is mapped to date indicates that it is located in or very near the Planning Area, if not directly below it, and thus presents a risk to generate a tsunami as well, see Map 4.4-4 and Map 4.4-5. This is discussed in more detail below in the Landslide Sources: Worst Case Scenarios below.

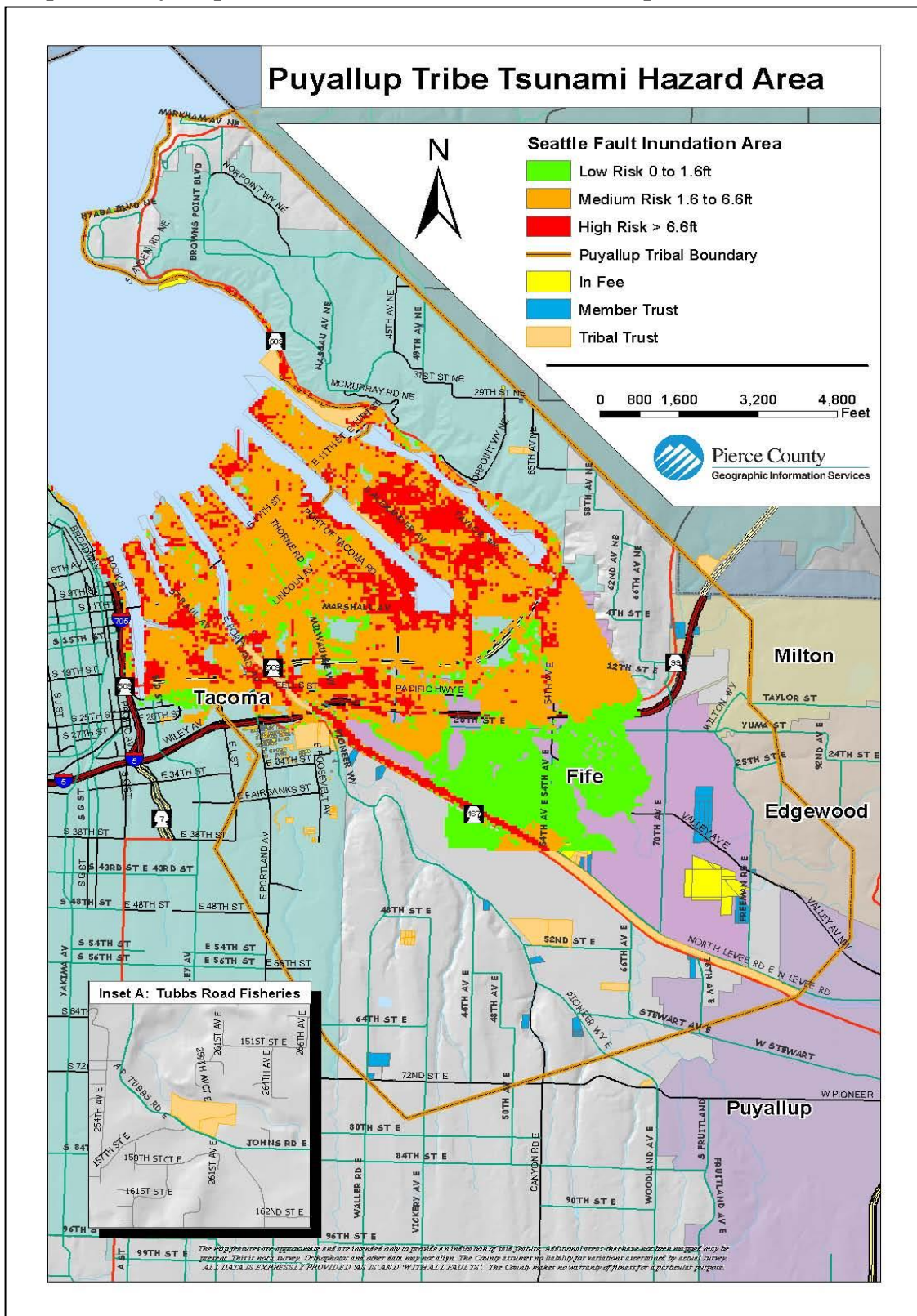
Landslide Sources

The same factors that contribute to the Planning Area's vulnerability to landslides contribute to its vulnerability to tsunamis. The occurrence of rapidly increasing development near or on waterfront bluffs makes these areas vulnerable to landslides. Thus areas along the northern side of Commencement Bay are increasingly vulnerable to landslides. With increasing development and the creation of the new Tacoma-Narrows Bridge, this vulnerability should continue to rise. Areas of particular higher vulnerability include Pt. Fosdick (the southern tip of the Gig Harbor peninsula) and Fox Island. The result is that both the cause of a tsunami (landslide) and the population which a tsunami could inundate are both rising, resulting in the Planning Area and the entire region becoming increasingly more vulnerable to the tsunami hazard.

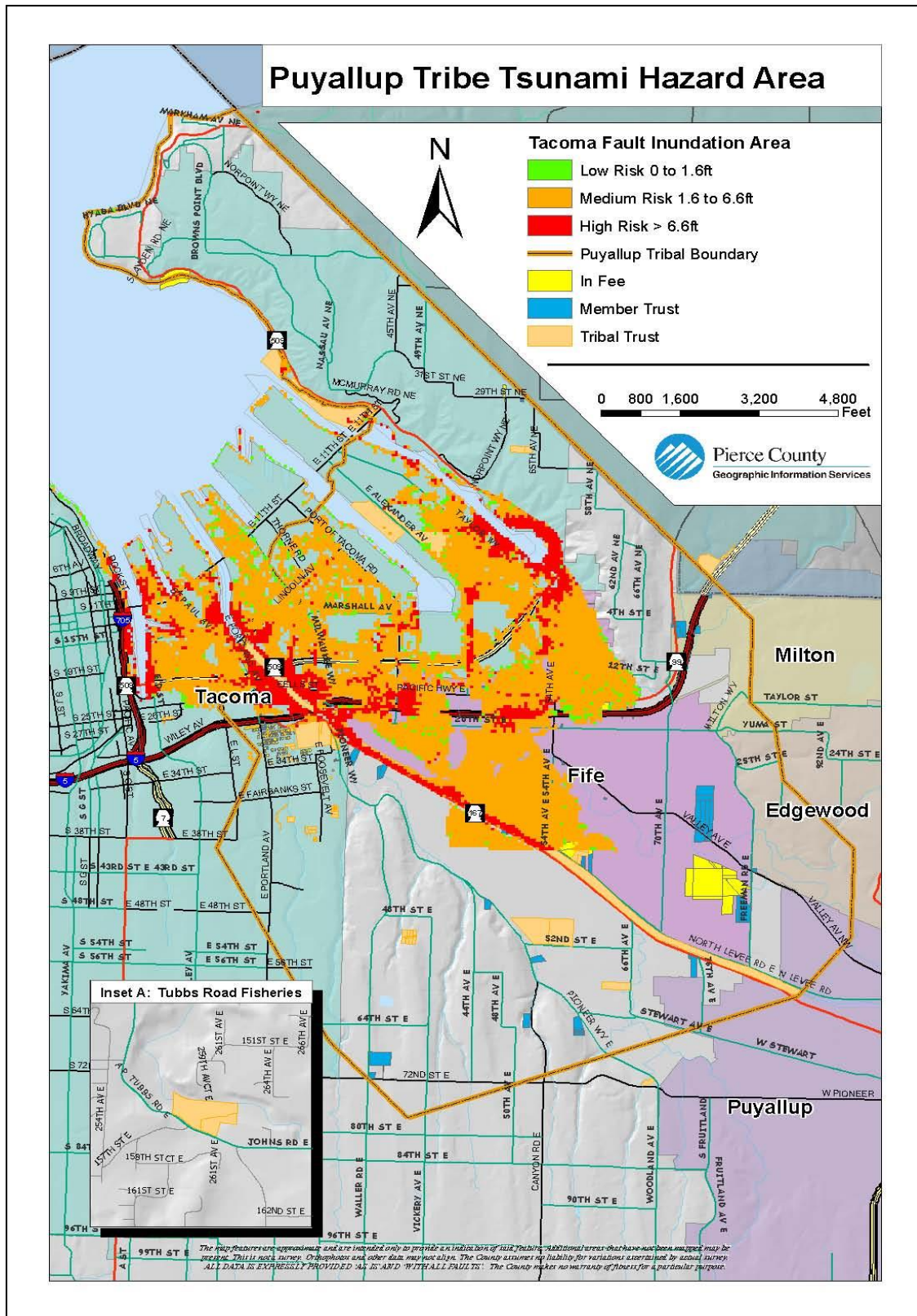
Map 4.4-2 Washington State Tsunami Vulnerability²⁵



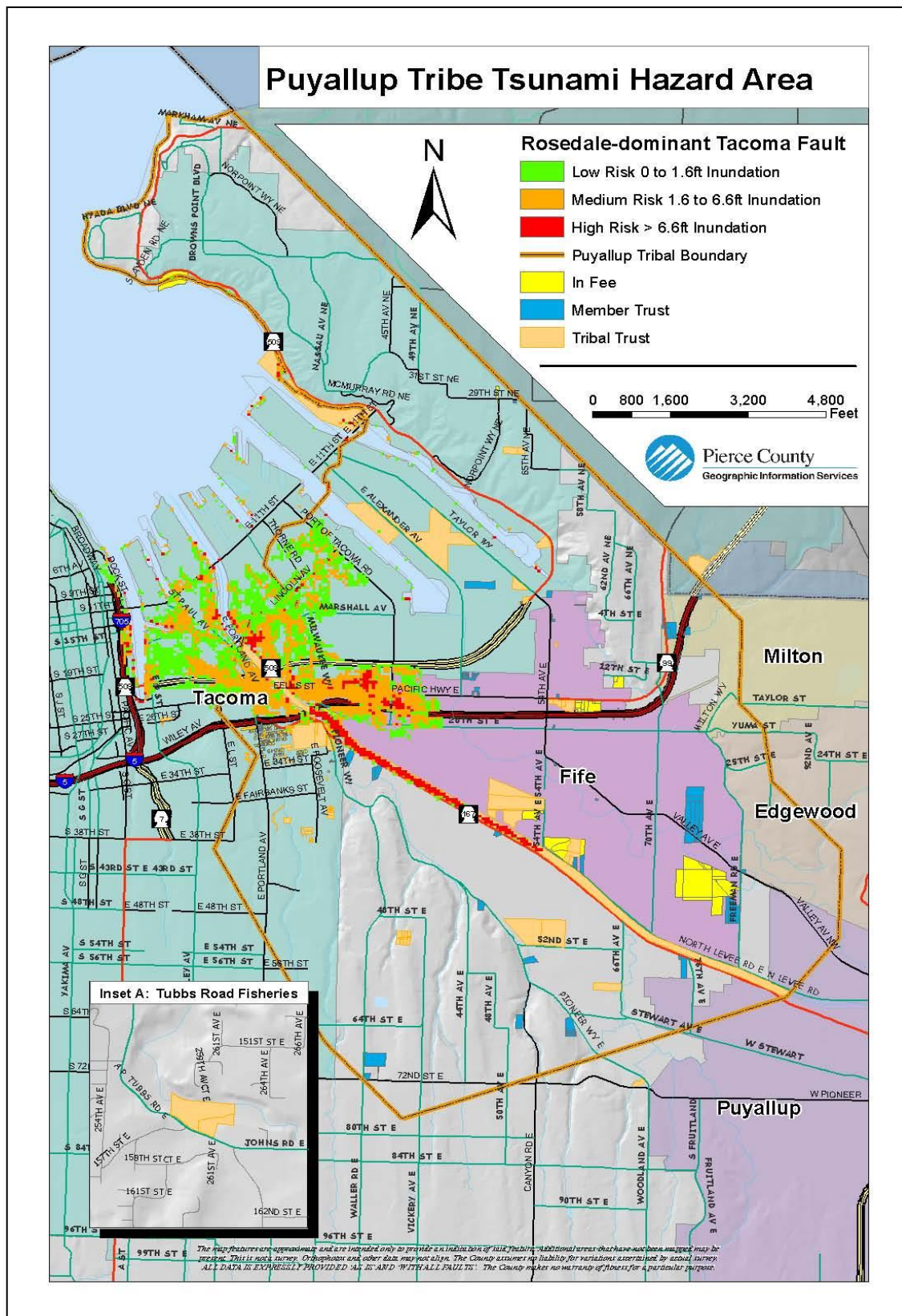
Map 4.4-3 Puyallup Tribe of Indians Seattle Fault Earthquake Scenario26



Map 4.4-4 Puyallup Tribe of Indians Tacoma Fault Earthquake Scenario²⁷



Map 4.4-5 Puyallup Tribe of Indians Rosedale-dominant Tacoma Fault Earthquake Scenario²⁸



As further guidance for the tsunami vulnerability assessment, landslides at Puget Sound can be envisioned in several scenarios: landslides with historical precedent in Puget Sound, credible “worst case” landslides based on analogies with other places, and submarine slides not associated with river deltas.

Scenarios²⁹

Scenario landslides based on local historical precedent offer the great advantage of having dimensions and effects like those known to have occurred at Puget Sound.

Historical Precedent Scenarios

The first kind of scenario is based on tsunami-causing Puget Sound landslides such as the 1894 Commencement Bay delta failure and the 1949 Tacoma Narrows subaerial landslide. The geometry of each is well defined from field observations.

Ground shaking in the port area of Tacoma during the Nisqually earthquake was less than 0.1 g peak ground acceleration and of short duration; this seismic loading was at or below the threshold necessary to generate liquefaction in the worst soil conditions. One hallmark of this earthquake was the paucity of subaerial landslides, likely the result of the severe drought conditions that preceded the event. However, the slopes adjacent to the Salmon Beach landslide triggered by the 1949 Olympia event did fail. If soil moisture conditions were nearer normal, this landslide might have been large enough to reach the Sound and generate a splash wave as was generated in 1949.

Worst-Case Scenarios

“Worst-case” scenarios for landslides at Puget Sound can be explored by means of analogy with landslides in similar settings elsewhere. For example, as a starting hypothesis, tsunami modelers could assume a landslide about one-third the volume of the 1964 Valdez slide—a giant delta-front failure triggered by the 1964 Alaska earthquake. This particular worst case could be modeled as a delta slope, submarine, or subaerial occurrence. In all cases, however, it probably needs a large earthquake as a trigger. And because the recurrence of large shallow earthquakes on faults at Puget Sound is poorly known at best, defining the likelihood for outsize failures will ultimately depend on better definition of prehistoric earthquake recurrence.

The Valdez Arm is a long east-west oriented fjord that terminates at the (former) town of Valdez, where it is approximately 3 miles (5 km) in width. A large delta formed by the Lowe and Robe rivers and a large stream flowing from the Valdez Glacier occupies the east end of the fjord, which was the former site of the town of Valdez. They report a total landslide volume estimated at 96 million cubic yards (74 million cubic meters). The delta slopes to a depth of 600 ft at the bottom of the fjord approximately 2 miles west of the tide flat. The total perimeter of the landslide is approximately 2500 m, and the top to toe distance is about 1200 m; these dimensions require an average thickness of about 25 m. Consequently, one possible geometry of a landslide that is only one third the volume of the Valdez failure would have a width of 1700 m, a thickness

of 20 m, and a top to toe length of 800 m.

Could such a landslide fit into the Puyallup River deltas? Commencement Bay is at the head of a fjord that had been significantly filled with sediment during the mid to late Holocene. The large delta deposited by the Puyallup River occupies the head of this flooded fjord, similar in setting to the delta at the head of Valdez Arm. The floor of the fjord in Commencement Bay is at a depth of approximately 450 ft, somewhat shallower than at Valdez.

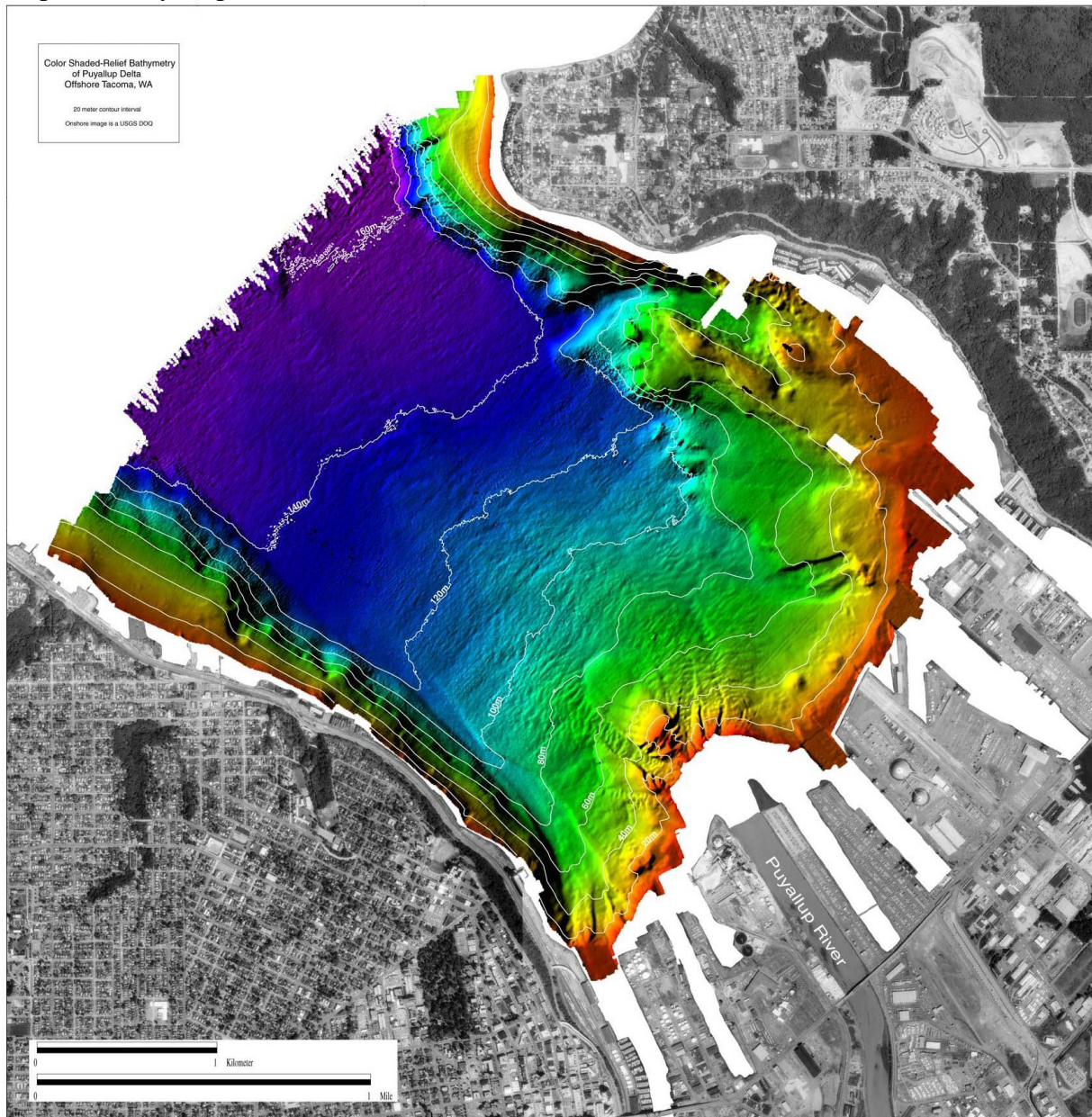
Because of the shallower depth of the Commencement Bay floor, the top to toe distance of the proposed “worst-case” submarine landslide scenario must be decreased to a distance of 500 m. To accommodate this decrease, the perimeter and thickness of the scenario landslide can be set to 2000 m and 25 m, respectively. These small changes yield a landslide volume of 25 million cubic meters, roughly one third of the volume of the 1964 Valdez failure.

Commencement Bay is approximately 2.5 miles wide, and similar in width to Valdez Arm. This is more than sufficiently wide to accommodate the “worst-case” delta failure scenario. The Puyallup River is largely free flowing with its water and sediment source originating from Mt. Rainier glaciers. Because of anthropogenic changes to the White/Stuck River channels, sediment supply to the Puyallup delta has significantly increased in the last 100 years. The history of delta landslides (1894 and 1943) clearly indicate the instability of this location.

Probability of Worst Case

The Puyallup delta has a rich history of small and moderate-sized failures, and this represents only a 110-year historic record. If delta failures behave like other natural phenomena (e.g., floods or earthquakes), then this short history suggests that the recurrence of an 1894 failure on this delta is relatively frequent on a geologic timescale. Prediction of the recurrence of this failure using statistical methods would no doubt yield a recurrence in the hundreds or few thousands of years, with large uncertainty. Although the historic Puyallup delta failures were non-seismogenic, the “worst-case” event on the Puyallup delta would likely have a seismic trigger; in this case, the appropriate question would be: “What is the recurrence of major earthquakes on nearby fault structures, especially the Tacoma Fault?” As the answer to this question is currently unknown, so too is the probability of a worst-case Puyallup delta failure event.

Map 4.4-6 Puyallup River Delta³⁰



Non-Deltaic Submarine Slide Scenarios

Historic large landslides in Puget Sound tend to be located near Quaternary faults that cross Puget Sound. There are no historical records of these slides, and it is unknown whether they generated tsunamis.

The occurrence of rapidly increasing development near or on steep slopes throughout the Planning Area and region makes these areas vulnerable to tsunamigenic landslides. Thus areas

throughout the peninsula are increasingly vulnerable. With increasing development and the creation of a new bridge, this vulnerability should continue to rise. Also, as the Port continues its industrial expansion, the Tribe's natural resource interests become more vulnerable to spills and pollution caused by tsunami damage.

Planning Area

The Planning Team determined that the Planning Area has a low vulnerability to tsunami hazard because of the probability of recurrence and the development patterns along coastal areas. This is based on the scenario analyses above and local geographic conditions.

In the entire Planning Area, approximately 2,371 acres (12%) are vulnerable to the tsunami hazards identified by the Planning Team. The total damage to the Planning Area could equal approximately \$295 million (the assessed value of 568 parcels in the Planning Area).

Impacts

Health and Safety of Persons in the Affected Area at the Time of the Incident

The impacts to those in the area hit by a tsunami will depend directly on how large it is as well as its cause. If generated by a landslide into Puget Sound from one of the steep hillsides or cliffs bordering the Sound, or an underwater slide from the Puyallup Delta, the impacts would be limited compared to one generated by a large earthquake on either the Seattle or Tacoma faults.

Depending on the location, direction that the wave propagates, time of day and even time of year, fatalities and casualties from any tsunami could be high within the impacted area. However, the method of generating the tsunami could dramatically affect the size of the impacted area.

This was the situation with the 1894 tsunami discussed above; see Figure 4.4-10 Damage in Tacoma from the 1894 Tsunami. One of the factors limiting fatalities and casualties in 1894 was the occurrence of the tsunami at night when the waterfront population was low.

Today, while many of the port facilities are better positioned to survive a wave of that magnitude, a repeat of the 1894 tsunami could damage berthed ships and cause major damage to the restaurants and businesses located on pilings along Ruston Way. In addition, businesses located along the waterways, like the marinas, could sustain extensive damage.

The effects from tsunamis generated by landslides from bluffs along the Sound would be limited in scope. Slides from bluffs are a regular occurrence along Puget Sound and very few of them are large enough to generate a wave of any size. Even a repeat of a slide the size of the 1949 Salmon Beach slide, see Figure 4.4-7, would most likely cause damage to homes or businesses in close proximity to the slide. Areas of particular concern are those with low bank access to the water, especially those facing a potentially unstable slope.

In contrast, if the tsunami is generated from a large earthquake on either the Tacoma or the Seattle faults, the damage could be severe enough from the tsunami itself with many deaths and injuries. Evacuation routes could be blocked either by landslides, power lines or other debris. People could be trapped in damaged buildings along the waterfront and not be able to evacuate before a tsunami arrives. In addition, the destruction to the infrastructure from the earthquake could prevent easy evacuation from areas threatened by the tsunami. In a situation like this, fire, police, and other responders will not be able to adequately rescue or assist citizens with the resources normally at hand.

Puget Sound tsunamis could damage both facilities located along the coast and rail cars traveling along the coastal tracks. Many of these contain hazardous materials that could be released into the environment. The resulting spills would contaminate not only the areas initially hit by the wave but also, due to tides within Puget Sound, the coastline of Pierce and neighboring counties. Depending on the chemicals released this could pose a threat to citizen's health for weeks or even longer.

It is possible that bridges and ferry docks hit by the tsunami could be damaged; either partially or fully destroyed. This would limit the ability of citizens to evacuate the individual islands in Pierce County and in the case of the Purdy Bridge limit access to the Longbranch Peninsula.

Health and Safety of Personnel Responding to the Incident

Response personnel located within the affected area will have the same threats as the general population during the actual period of time that the waves are active and dangerous. In addition, first responders, due to the nature of their work, potentially could be repeatedly putting themselves in contact with the hazardous environment consisting of chemical spills, debris, downed power lines in water, etc. as they perform their jobs.

Continuity of Operations and Delivery of Services

The adverse impact to jurisdictions within Pierce County for a non-earthquake generated tsunami, in maintaining normal day-to-day operations, will be limited. Damage and response will both be limited due to the small size and localized effect of the tsunami.

The exception is for large tsunamis associated with a major earthquake on either the Tacoma or Seattle fault. Computer modeling shows wave action and related currents moving deep into Gig Harbor, the Port of Tacoma, Fife, and reaching over five kilometers up the Puyallup River;³¹ see Figure 4.4-4 Tsunami Inundation and Current-Based on Earthquake Scenario. Due to the size and area covered during a run up it is probable that one of these tsunamis would impact and damage the infrastructure and equipment in the Port of Tacoma and the infrastructure of some other coastal jurisdiction; see Page 19 Property, Facilities, and Infrastructure. Damage to cranes, docks, and even the Port Administration Building are all possible from a large locally generated tsunami. In this case the Port would not have the ability to maintain normal operations. For other jurisdictions the tsunami will probably have less direct effect on their ability to maintain operations. Instead any operational continuity will be impacted more from the earthquake itself.

The impact to a jurisdiction's ability to deliver services is directly related to their proximity to Puget Sound. Damage throughout the coastline of Pierce County will not usually impact the delivery of services to citizens, residences, or businesses with a few exceptions. Damage to the ferries, ferry docks, or bridges to some islands will limit or in some cases prevent normal County services, possibly for an extended period of time.

Damage to the Port of Tacoma's infrastructure and equipment, in limiting its ability to operate at maximum efficiency, will lead to an inability to deliver the services normally provided to the lessees. Such damage could affect the ability of the Port to maintain itself as one of the major ports on the West Coast. An inability to maintain normal service delivery for any extended period of time could result in the loss of companies to competing Ports, either in Seattle or depending on the type of goods, any other major port on the West Coast.

Loss of power due to damage to electric power stations is possible, especially to the Bonneville Power Administration substation located at the south end of the Hylebos Waterway. Rail lines in the Port and along Ruston Way and running south from Salmon Beach could sustain damage.

Within the City of Tacoma, Marine View Drive/Hwy 509, Ruston Way and Schuster Parkway are all major routes that could sustain tsunami damage. Portland Avenue running along the Puyallup River and Dock Street on the Foss Waterway are both examples of streets that could be inundated but are not part of the Port of Tacoma. The most likely bridge to be damaged is the Lincoln Avenue Bridge. All of these routes mentioned, if damaged or destroyed, would have a negative impact on the delivery of services to the community. In addition, there could be damage to City fire facilities including fire boats and the two stations located on Ruston Way and the Foss Waterway.

Sewage treatment plants located at or near tidewater have a high probability of damage. In this case the City of Tacoma's treatment plant on the Tacoma tide flats could be damaged by a tsunami. In addition, the underside of bridges sometimes carry water, gas, and other lines that cross the Puyallup River and a high wave could damage these.

Due to local topography, University Place, Steilacoom and DuPont, while all located along the coast, only have a small portion of their populations within reach of a tsunami. Sunset Beach and Day Island in University Place are the two areas most likely to sustain damage. A tsunami inundating either area could damage or destroy most of the houses, and in the case of Day Island, the marina as well. Damage from the tsunami could damage the roads in both areas, however, if the tsunami is big enough to do this type of damage, outside of immediate emergency response, there is little in the way of service delivery that will be needed until the area is rebuilt.

Gig Harbor is slightly different from the standpoint that much of the downtown or economic core of the City is located along the shore of the Harbor. The Harbor with its narrow entrance opening into a wider bay may in some cases dissipate some of the waves that enter it. However, recent research suggests that an earthquake along the Tacoma Fault could send a 0.7 meter wave into the Harbor.³² An earthquake along the Seattle Fault can do even more damage to Gig Harbor. Computer modeling shows that an earthquake on the Seattle Fault could send a 3.5 meter wave into downtown Gig Harbor.³³ While a 0.7 meter wave would cause some damage within the

Harbor, especially to boats and docks, it is doubtful that it would cause further damage within the City itself. A 3.5 meter wave on the other hand will not only wreck havoc among the boats moored within the Harbor itself, but also along the streets paralleling the shore line blocking them with debris, disrupting power and making response very difficult. Due to the rapid increase in elevation by the landscape above the waterfront, services should not be impaired by the tsunami itself throughout most of the City. As the shoreline is put back in order services will be able to be resumed.

The other area that could have problems with the delivery of services is the City of Fife. While not a coastal community, its proximity to the coast, the Blair and Hylebos waterways extending almost to its borders, its position on the Puyallup River and its low elevation all leave it susceptible to damage from tsunamis. Material, including hazardous chemicals carried into Fife from the Port of Tacoma, could render response or the delivery of any kind of services within the City nonexistent.

Property, Facilities, and Infrastructure

Property impacts from a Puget Sound tsunami could range from minor to extreme. For example, a small tsunami generated by a landslide off the steep hillsides in the southern portion of the Sound either in or south of the Tacoma Narrows would affect only a small population that live right along the water front and a few businesses like the Day Island Yacht Harbor. However, even with a small tsunami here there could be an infrastructure problem in that the Burlington Northern Railroad tracks run along the coast. Damage to the tracks would put a temporary stop to rail traffic, both cargo and passenger, between Tacoma and Portland.

In contrast, a large earthquake generated on the Tacoma or Seattle faults could send a tsunami throughout the entire Port of Tacoma area as well as up the Puyallup River, through Fife, overtopping the levees along sections of the Puyallup River causing further flooding along sections of the lower Puyallup. In addition, due to the volumes of water there would be extensive damage from currents along not just the waterways, but also inland as the water flowed back to the Sound carrying debris with it.

Damaged property and infrastructure in this case would not just be the private property and businesses, but roads, both local and major like Highways SR-509, SR-99 and possibly I-5. Damage to the levees along the Puyallup could cause further problems with flooding in future storms. Ships docked in the Port could be damaged as they are moved by the waves and currents. Chemical companies would be damaged, possibly including spills of large quantities of hazardous chemicals that could spread pollution over a large area. Bonneville Power Administration has a major electric power substation located at the south end of the Hylebos Waterway that could have major damage if it was inundated by a high wave (couple of meters) of salt water. Rail lines in the Port could be damaged. The City of Tacoma's sewer treatment plant is vulnerable as are water, gas, and other lines that cross the Puyallup River on the underside of bridges.

Roads along the waterways could be heavily damaged. These include Marine View Drive, Ruston Way and Schuster Parkway. Businesses along these roads could be destroyed or heavily

damaged. This includes the restaurants and others along Ruston Way, the grain elevator and loading facilities on Schuster and the marinas currently home to hundreds of boats.

In these scenarios, Gig Harbor will also receive a wave causing damage to docks, boats, and businesses as will portions of the rest of the Sound south of the Narrows.

The Environment

The environmental impacts from a tsunami striking Pierce County could range from very minor to catastrophic. A small tsunami, like the 1949 wave, would cause very limited environmental damage unless it caused a significant chemical spill. This could happen if it derailed a train carrying hazardous chemicals traveling along the waterfront. In most cases the damage would be to the beach covering at the point of the slide and the animals that reside there, erosion from the wave action, and damage to the vegetation directly in the path of the wave's run-up.

At the other extreme a tsunami originating either in Commencement Bay, perhaps from a rupture of the Tacoma Fault, or a large one traveling down Puget Sound from a rupture on the Seattle Fault could damage ships in port. It could destroy the oil and gas tanks at the entrance to the Foss Waterway and damage a number of other properties throughout the port, many of which have quantities of hazardous chemicals. Tides could carry those chemicals throughout not just Commencement Bay, but into other portions of Puget Sound as well. In this case the damage could be catastrophic and depending on the type and quantity of chemical(s) released the environmental damage could last for years if not decades.

Water overrunning the Port, extending into Fife and extending up the Puyallup River overtopping the levees will leave a residue of salt, and possibly other chemicals picked up by the water's passage through the Port, that could affect agriculture for years if not decades.

Economic and Financial Condition

We can break the potential for tsunami economic impacts into three groups by size. While there are no exact size parameters we will use the 1949, 1894, and a tsunami generated by either the Tacoma or Seattle faults.

Small tsunamis similar to 1949 or smaller would have very limited or no impact on the economic or financial condition of the jurisdictions located in Pierce County. Their area of impact will be restricted because the volume of water displaced is very limited. There could be more damage from the actual landslide than from the tsunami itself depending on where the slide occurs.

A repeat of 1894 could cause greater damage with a wave damaging or destroying many of the businesses along both Ruston Way and Marine View Drive as well as some in the Port of Tacoma and the Foss Waterway. In this case, damage could run into the millions.

The third scenario would be a large tsunami from a quake on either the Tacoma or Seattle fault. The developing tsunami could devastate large portions of the Pierce County coastline. In a situation of this magnitude, actual losses from the tsunami itself could be many times that of the

previous scenarios. The damage to businesses located in the Port of Tacoma, perhaps as far as Fife, combined with the losses along Ruston Way, Gig Harbor and other points along the coast could set back the economic base for years. Many businesses and a large portion of the industrial base of the County would be damaged. Thousands of jobs would be lost, and tax revenues would drop. It could take years to repair all the infrastructure and only then could the economy begin to rebuild to pre-earthquake/tsunami levels.

Public Confidence in the Jurisdiction's Governance

Depending on the amount of damage, from a locally generated tsunami, the public's confidence in the jurisdiction's governance could be sustained or adversely affected. A large tsunami generated by either the Tacoma or Seattle faults could cause extensive damage all along the Pierce County coastline, throughout the Port of Tacoma, and possibly some distance up the Puyallup River. Even with a case like this the public's confidence in a jurisdiction would be governed by people's perceptions of how well the response and recovery went. A well coordinated, visible, response and recovery effort will increase citizen confidence in their local government. In contrast, a poorly coordinated one will decrease the public confidence in the local jurisdiction's competence.

Resource Directory

Regional

- **Pierce County Department of Emergency Management**
<http://www.co.pierce.wa.us/PC/Abtus/ourorg/dem/abtusdem.htm>
- **USGS Western Region Coastal and Marine Geology**
<http://walrus.wr.usgs.gov/pacmaps/site.html>
- **Washington State Emergency Management Division**
http://www.emd.wa.gov/hazards/haz_tsunami.shtml
- **Washington State Department of Natural Resources**
<http://www.dnr.wa.gov/ResearchScience/Topics/GeologicHazardsMapping/Pages/tsunamiis.aspx>

National

- **Pacific Tsunami Museum**
www.tsunami.org
- **USGS Tsunami and Earthquake Links**
<http://walrus.wr.usgs.gov/tsunami/links.html>
<http://www.usgs.gov/hazards/>
- **Pacific Tsunami Museum Links**
<http://www.tsunami.org/links.htm#Tsunami%20Resource%20Centers>
- **National Weather Service Tsunami Warning System**
<http://www.tsunamiwave.info/>
- **NOAA Tsunami Research Program**
<http://nctr.pmel.noaa.gov/>
<http://nctr.pmel.noaa.gov/animate.html>
<http://nctr.pmel.noaa.gov/pugetsound/pre2/movie/ps.html>
- **Interactive Tsunami Site**
<http://www.geophys.washington.edu/tsunami/welcome.html>
- **International Tsunami Journal**
<http://www.sthjourn.org/>

Endnotes

¹ Pacific Tsunami Museum Archive Photos <http://www.tsunami.org/archivesmore1946.htm>. [Internet accessed February, 2004].

² Pacific Tsunami Museum Archive Photos <http://www.tsunami.org/archivesmore1946.htm>. [Internet accessed February, 2004].

³ Modified from Washington State Natural Hazard Mitigation Plan (DRAFT), Tsunami Section, Washington State Emergency Management Division. September 5, 2002.

⁴ Gonzalez, Frank I., et al. "Puget Sound Tsunami Sources: 2002 Workshop Report." NOAA/Pacific Marine Environmental Laboratory, Contribution No. 2526, 2003. p. 9-14.

⁵ Landslides situated, formed or occurring on the surface of the earth.

⁶ *Ibid.* p. 6.

⁷ NOAA Technical Memorandum OAR PMEL-132, Tacoma, Washington Tsunami Hazard Mapping Project: Modeling Tsunami Inundation from Tacoma and Seattle Fault earthquakes. Venturato, Angie J., et al, NOAA, United States Department of Commerce January 2007, p 3.

⁸ *Ibid.* p.3.

⁹ Tacoma, Washington, Tsunami Hazard Mapping Project: Modeling Tsunami Inundation from Tacoma and Seattle Fault Earthquakes, NOPP Technical Memorandum OAR PMEL-132, Venturato, Angie J. et al., pps. 9-10.

¹⁰ Tacoma, Washington, Tsunami Hazard Mapping Project: Modeling Tsunami Inundation from Tacoma and Seattle Fault Earthquakes, NOPP Technical Memorandum OAR PMEL-132, Venturato, Angie J. et al., pps. 9-10.

"Due to constraints of the inundation grid, the model does not cover the full extent of wave propagation in the upper Puyallup River; subsequently, the wave reflects off the edge of the grid boundary leading to potentially nonphysical inundation within the City of Fife and Puyallup Nation territory."

¹¹ *Ibid.* p. 13.

¹² *Ibid.* p.11.

¹³ *Ibid.* p. 9-14.

¹⁴ Tacoma News Tribune, April 18, 1949. p.1 as quoted in Lander, et al. (1993) *Tsunamis Affecting the West Coast of the United States 1806-1992*, NGDC Key to Geophysical Record Documentation No. 29, NOAA, NESDIS, NGDC, 242 pp. at http://wcatwc.arh.noaa.gov/web_tsus/19490413/references.htm

¹⁵ *Ibid.* Cover.

¹⁶ Modified from PC HIVA, Landslide Section, September 5, 2002, p.37.

<http://www.co.pierce.wa.us/xml/abtus/ourorg/dem/HIVAWEB.pdf>

¹⁷ Western Regional Coastal and Marine Geology. USGS. <http://walrus.wr.usgs.gov/pacmaps/images/puycomp.jpg> [Accessed Internet January, 2004].

¹⁸ Gonzalez, Frank I. et al., Puget Sound Tsunami Sources: 2002 Workshop Report, A Joint Special Report: National Oceanic and Atmospheric Administration, United States Geological Survey, Washington State Department of Natural Resources, Washington State Military Department Emergency Management Program, June 2003, p.10

¹⁹ Modified from Washington State Natural Hazard Mitigation Plan (DRAFT), Tsunami Section, Washington State Emergency Management Division. September 5, 2002.

²⁰ Tacoma, Washington, Tsunami Hazard Mapping Project: Modeling Tsunami inundation from Tacoma and Seattle fault Earthquakes, Venturato, et.al., United States Department of Commerce, National Oceanic and Atmospheric Administration, Office of Oceanic and Atmospheric Research, January 2007, p. 3.

²¹ Damage to the docks from the 1894 tsunami generated by an underwater landslide in Commencement Bay. Photo from Archives in the Tacoma Public Library, Photo G27.1-099.jpeg

²² *Ibid.*

²³ Modified from PC HIVA (DRAFT), Landslide Section, September 5, 2002, p. 1.

<http://www.co.pierce.wa.us/pc/abtus/ourorg/dem/EMDiv/HIVA/TSUNAMI.pdf>

²⁴ Modified from Washington State Natural Hazard Mitigation Plan (DRAFT), Tsunami Section. Washington State Emergency Management Division. September 5, 2002.

²⁵ Washington At-Risk Population and Tsunami Modeling Status Map, from the National Oceanic and Atmospheric Administration Pacific Marine Environmental Laboratory's National Tsunami Hazard Mitigation Program, <http://www.pmel.noaa.gov/tsunami/time/wa/population/index.shtml>.

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- ²⁶ Tacoma, Washington, Tsunami Hazard Mapping Project: Modeling Tsunami Inundation from Tacoma and Seattle Fault Earthquakes, NOPP Technical Memorandum OAR PMEL-132, Venturato, Angie J. et al., pps. 9-10.
- ²⁷ Tacoma, Washington, Tsunami Hazard Mapping Project: Modeling Tsunami Inundation from Tacoma and Seattle Fault Earthquakes, NOPP Technical Memorandum OAR PMEL-132, Venturato, Angie J. et al., pps. 9-10.
- ²⁸ Tacoma, Washington, Tsunami Hazard Mapping Project: Modeling Tsunami Inundation from Tacoma and Seattle Fault Earthquakes, NOPP Technical Memorandum OAR PMEL-132, Venturato, Angie J. et al., pps. 9-10.
- ²⁹ Gonzalez, Frank I., et al. "Puget Sound Tsunami Sources: 2002 Workshop Report." NOAA/Pacific Marine environmental Laboratory, Contribution No. 2526, 2003. p. 14-18.
- ³⁰ Western Regional Coastal and Marine Geology. USGS <http://walrus.wr.usgs.gov/pacmaps/ps-puy.html> [Accessed Internet January, 2004].
- ³¹ Venturato, et al., p.12
- ³² Tacoma, Washington, Tsunami Hazard Mapping Project: Modeling Tsunami Inundation from Tacoma and Seattle Fault Earthquakes, NOPP Technical Memorandum OAR PMEL-132, Venturato, Angie J. et al., p 14.
- ³³ Tacoma, Washington, Tsunami Hazard Mapping Project: Modeling Tsunami Inundation from Tacoma and Seattle Fault Earthquakes, NOPP Technical Memorandum OAR PMEL-132, Venturato, Angie J. et al., pps. 10-11.