

SUB-SECTION 4G.2

PUYALLUP TRIBE ALL HAZARD MITIGATION PLAN EARTHQUAKE HAZARD

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Identification Description

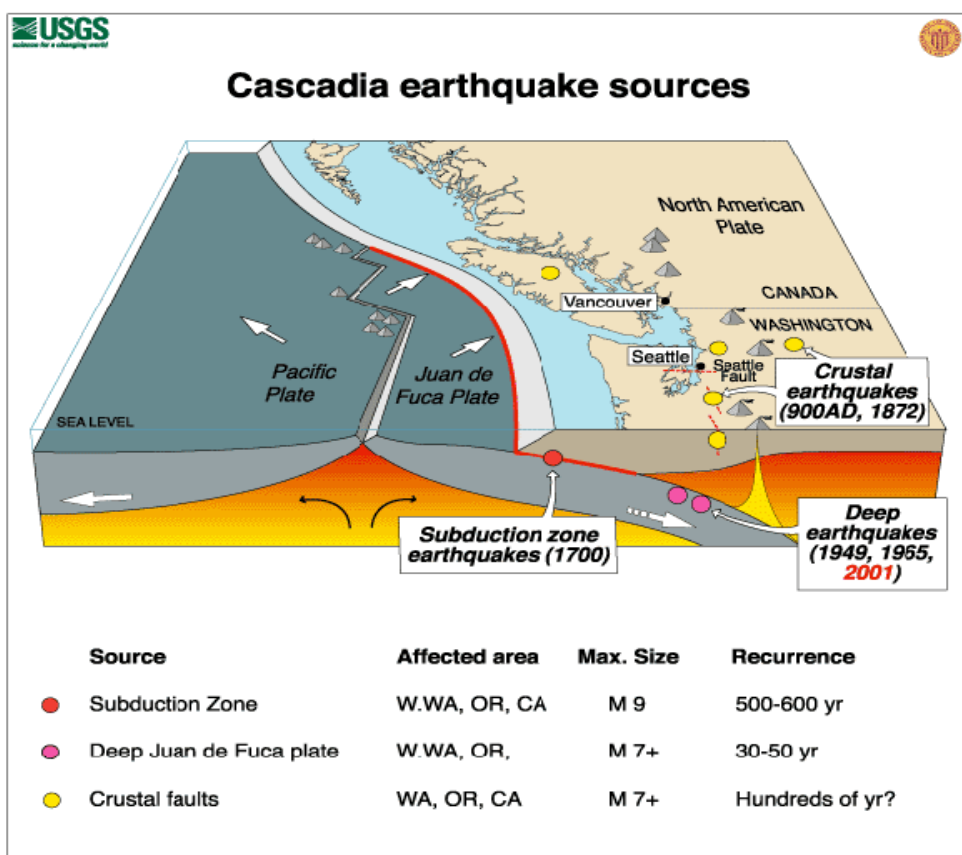
Definition¹

An earthquake is a naturally induced shaking of the ground. It is caused by an abrupt shift of rock along a fracture in the earth's crust called a fault. Within seconds, an earthquake releases stress that has slowly accumulated within the rock. Sometimes the release occurs near the surface and sometimes it comes from deep within the crust.

Types²

Washington is situated at the collisional boundary of two primary tectonic plates. The boundary where these two plates converge, the Cascadia Subduction Zone, lies approximately 50 miles offshore and extends from the middle of Vancouver Island in British Columbia to northern California. As it collides with North America, the Juan de Fuca plate slides (or subducts) beneath the continent and sinks into the earth's mantle. The collision of the Juan de Fuca and North American Plates produces the three main types of earthquakes discussed below and illustrated in Figure 4.2-1. A fourth type of earthquake not covered in detail here is produced by the movement of magma inside a volcano. These are generally small. Currently Mt. St. Helens has the best representation of them in the United States.

Figure 4.2-1 Types of Earthquakes³



Intraplate Earthquakes

Intraplate earthquakes in the Pacific Northwest are deep earthquakes. They lay, within a range of approximately 15 to 60 miles in depth and are within the subducting Juan de Fuca (oceanic) Plate. Most of the ones that impact Pierce County occur near or in an area where the Juan de Fuca Plate bends slightly as it slips beneath the North American (continental) Plate. These deep events typically have few, if any aftershocks. Intraplate earthquakes are the most frequent large events that strike Pierce County.

Crustal Earthquakes

Shallow crustal earthquakes occur primarily in western Washington, the northeastern flanks of the Cascade Range, and in the Columbia Plateau. These earthquakes occur primarily at depths of 20 miles or less. Since 1992, there is rapidly accumulating evidence that large crustal earthquakes occur on the Seattle Fault in areas of high population. In Pierce County there is ongoing research to understand the history and threat posed by the Tacoma Fault.⁴ As research continues, developing information on the nature of the risk from the Tacoma Fault will have a significant effect on hazard assessments for Pierce County.

Cascadia Subduction Zone Earthquakes

Cascadia Subduction zone (interplate) earthquakes occur less frequently than intraplate events, but probably more frequently than large crustal earthquakes. Because Cascadia earthquakes have a very large source (the fault could rupture along its entire length from Vancouver Island to northern California) the ground motion may last for four minutes in Pierce County and be of lower frequency than motions from earthquakes like the Nisqually (February 28, 2001). These long-periods of sustained ground motion, especially when combined with long period waves and soft soils, may be more damaging to large structures such as both of the Tacoma Narrows Bridges. Ground motion can be especially damaging to large buildings with complex designs, as opposed to many smaller buildings and homes.

Secondary hazards:

- **Liquefaction:** Soft soils or human-made fills can subside or experience liquefaction or lateral spreading in an earthquake. Liquefaction commonly causes lack of support for structures located on the liquefiable soils. You may have ground failures; ground cracking or boils from layers of sand sometimes located a number of meters under the surface. Lateral spreading is in fact a landslide that occurs on very shallow slopes due to the liquefiable nature of the soil. Noteworthy liquefaction took place in Puyallup during the 1949 earthquake and there were examples of it in both the 1965 and 2001 earthquakes. Liquefaction is directly related to the level of soil saturation combined with layers of sand. The sands that failed in Pierce County in many cases were sand deposits from Mount Rainier lahars, see *Map 4.2-2 Liquefaction in the Puget Sound Basin* and *Map 4.2-4 Pierce County Seismic Hazard*.
- **Landslides and Rockfalls:** These can be triggered on steep slopes. Earthquakes have caused large and disastrous landslides, including debris flows from volcanoes. Loss of

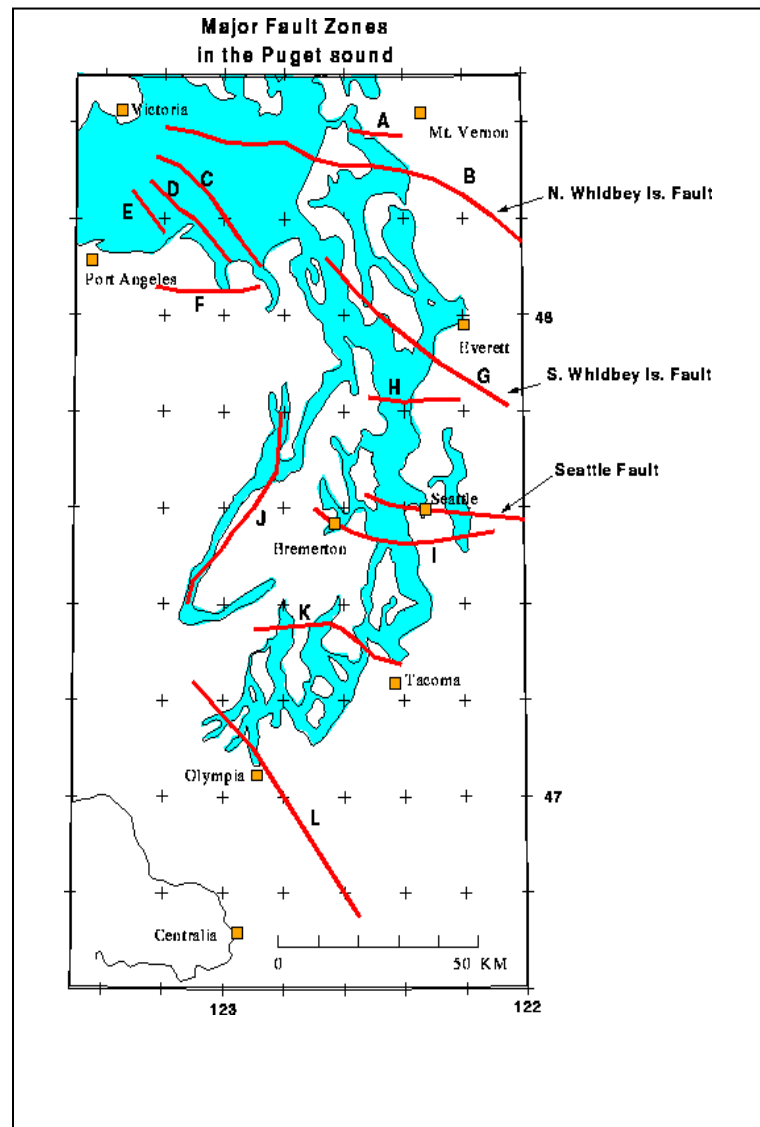
strength in sensitive, clay-rich soils can also cause landslides and other ground failures; see the Landslide and Volcanic Hazard Chapters of the Pierce County HIRA.

- **Dam Failure:** This is also a possibility during an earthquake. Likely causes are either a fracture of the retention wall or the failure of the soils under the structure. The Department of Ecology's inventory of dams lists 56 dams in Pierce County that, at peak storage, hold over ten acre-feet. This includes Mud Mountain Dam on the Pierce/King County border. In addition

Howard Hanson Dam on the Green River in King County could impact portions of Pierce County if it had a catastrophic collapse. Of these, 13 are considered to be high hazard, 15 are considered to be a significant hazard and 29 are listed as having a low hazard potential.

- **Levee Failure:** Levees in their role as a flood control feature exist to protect the land and the facilities on it from flood waters. Being largely built on liquefiable valley soils, damage to the levees is a real possibility. If an earthquake with resulting damage to levees happens during flood season, extensive flooding could occur before the levees were repaired. The real threat here is not to the levees themselves but if the river floods before the levee damage can be corrected the resulting threat is to the population, facilities and infrastructure situated behind those levees.

Map 4.2-1 Major Faults in the Puget Sound Basin



- **Tsunamis and Seiches:** Vertical displacement, co-seismic subsidence, or earthquake induced landslides can all cause tsunamis and seiches; see Tsunami Hazard Chapter of the HIRA.⁵

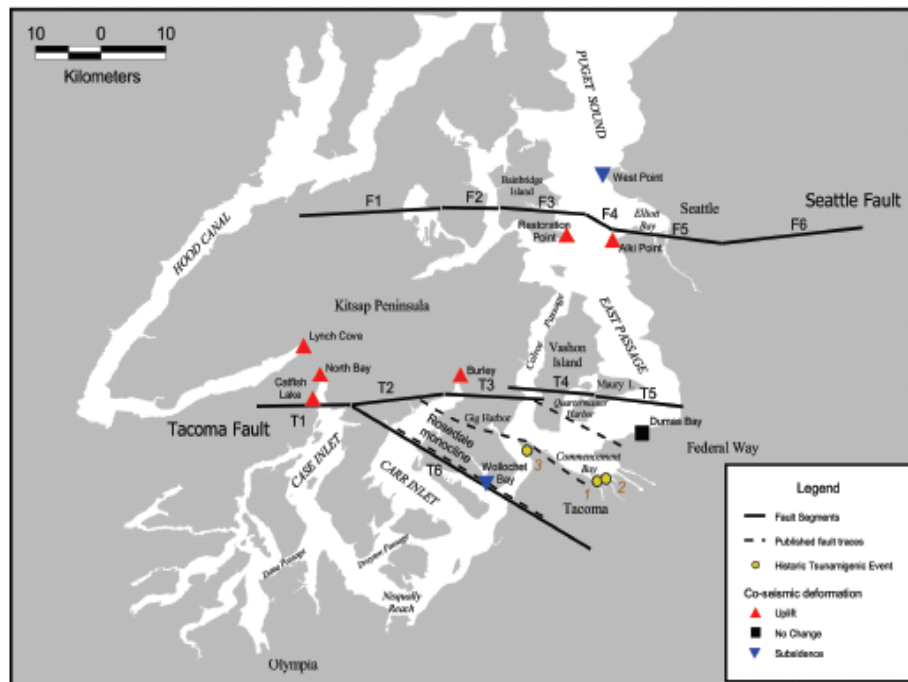
Profile

Location and Extent

Earthquakes directly and indirectly affect all of Pierce County and the Planning Area. To illustrate the earthquake risk in the County and the Planning Area, Figure 4.2-1, on page 2, shows the location of the various types of earthquakes that affect the Pacific Northwest. Map 4.2-1 shows the major faults in the Puget Sound. Map 4.2-2 shows the location of the Seattle Fault and the various branches of the Tacoma Fault and Map 4.1-3 shows the seismic hazard areas throughout Pierce County as defined by areas of liquefiable soils. Map 4.2-4 shows the seismic hazard area throughout the Planning Area.

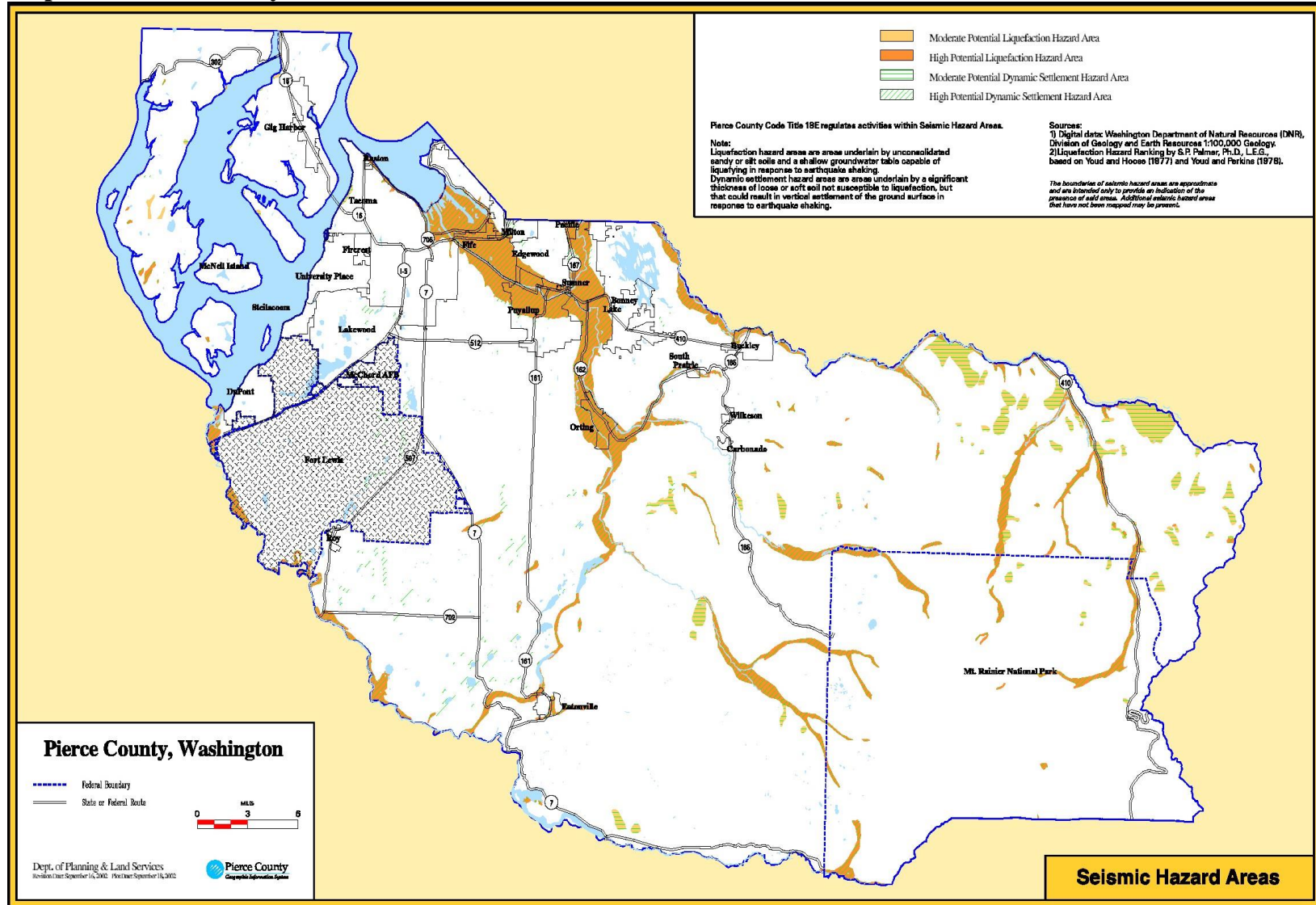
The scientific studies that have been done that created these maps state that the entire region is at risk to the earthquake hazard. Continuing updated information on the Tacoma Fault is revealing it and the surrounding geologic structure in greater detail yearly. One of the methods has been through the use of Light Detection and Ranging (LIDAR) mapping. The documented examples of these land-level changes date to about 1,100 years ago, though much remains to be learned about its extent and shape. As can be seen from Map 4.2-2 the various segments of the fault appear to run westward and northwestward from Tacoma across the Kitsap Peninsula.⁶ Ongoing research will continue to change our understanding of the Tacoma Fault and other local faults and their potential for a damaging earthquake to affect Pierce County.

Map 4.2-2 Seattle and Tacoma Fault Segments



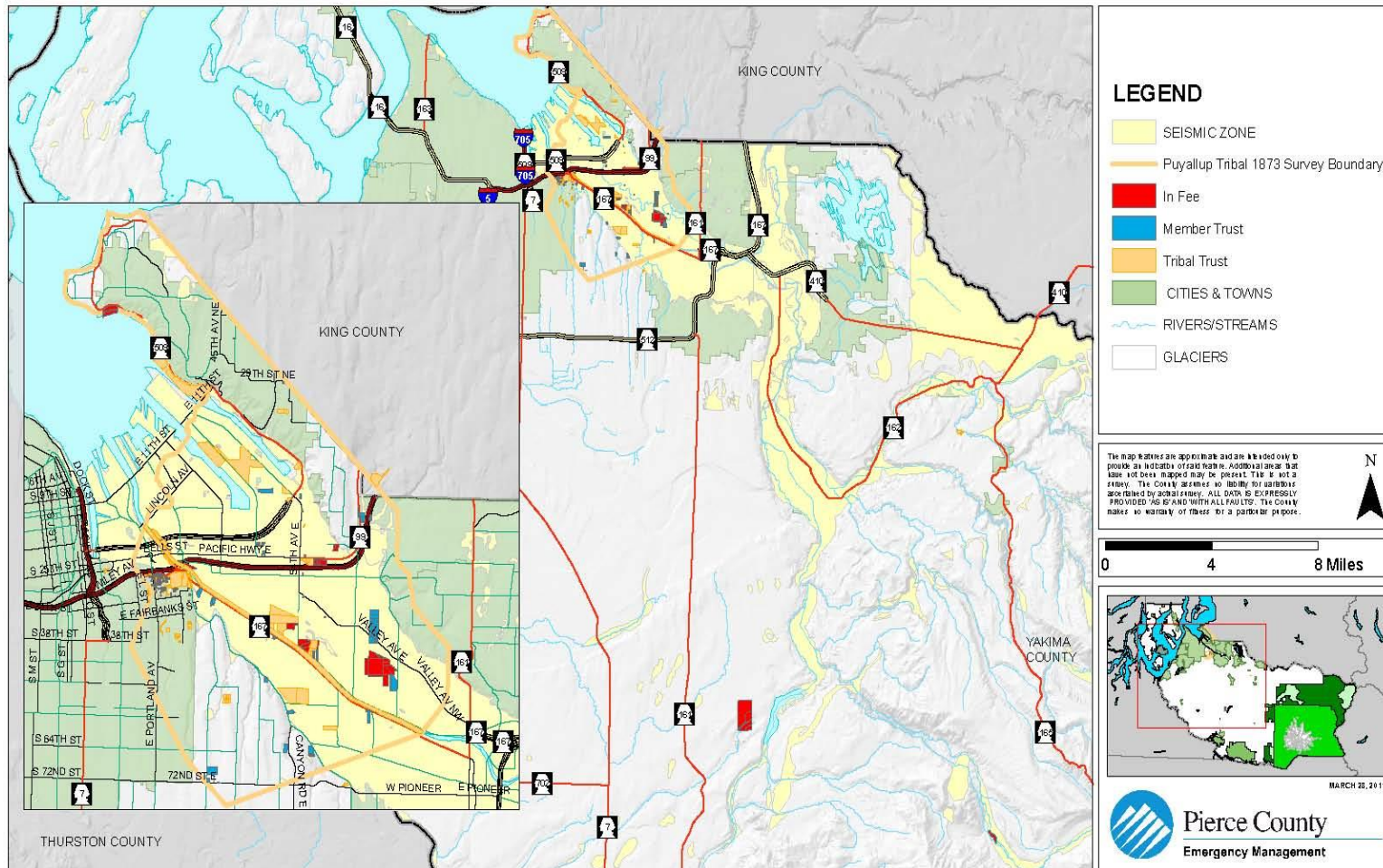
While the entire County experiences shaking during earthquakes, areas of liquefaction experience even greater shaking. Map 4.2-3 illustrates the location and extent of Pierce County's seismic hazard based on areas of liquefaction. As illustrated, the majority of liquefiable soils in

Map 4.2-3 Pierce County Seismic Hazard

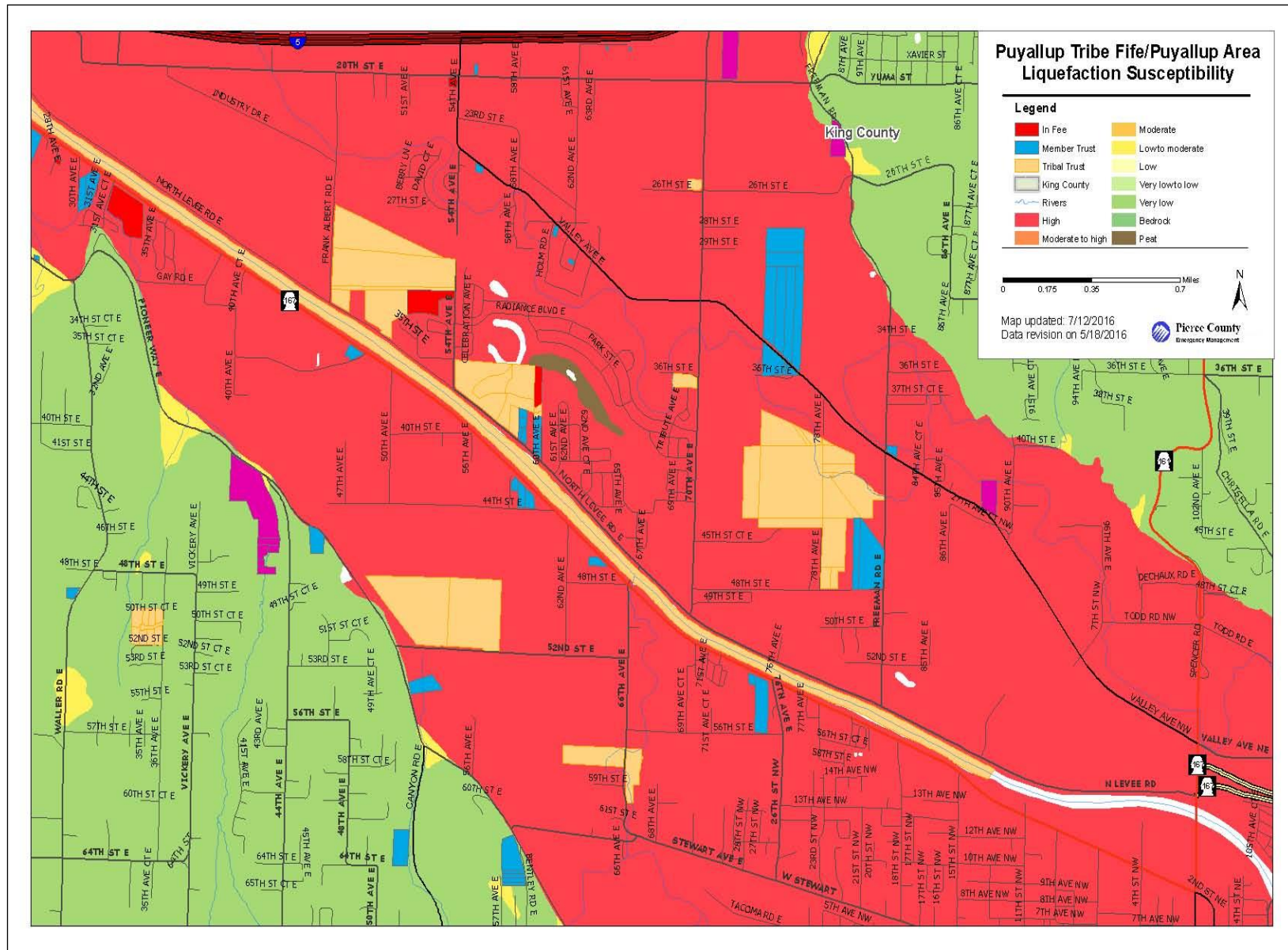


Map 4.2-4 Puyallup Tribe of Indians Seismic Hazard

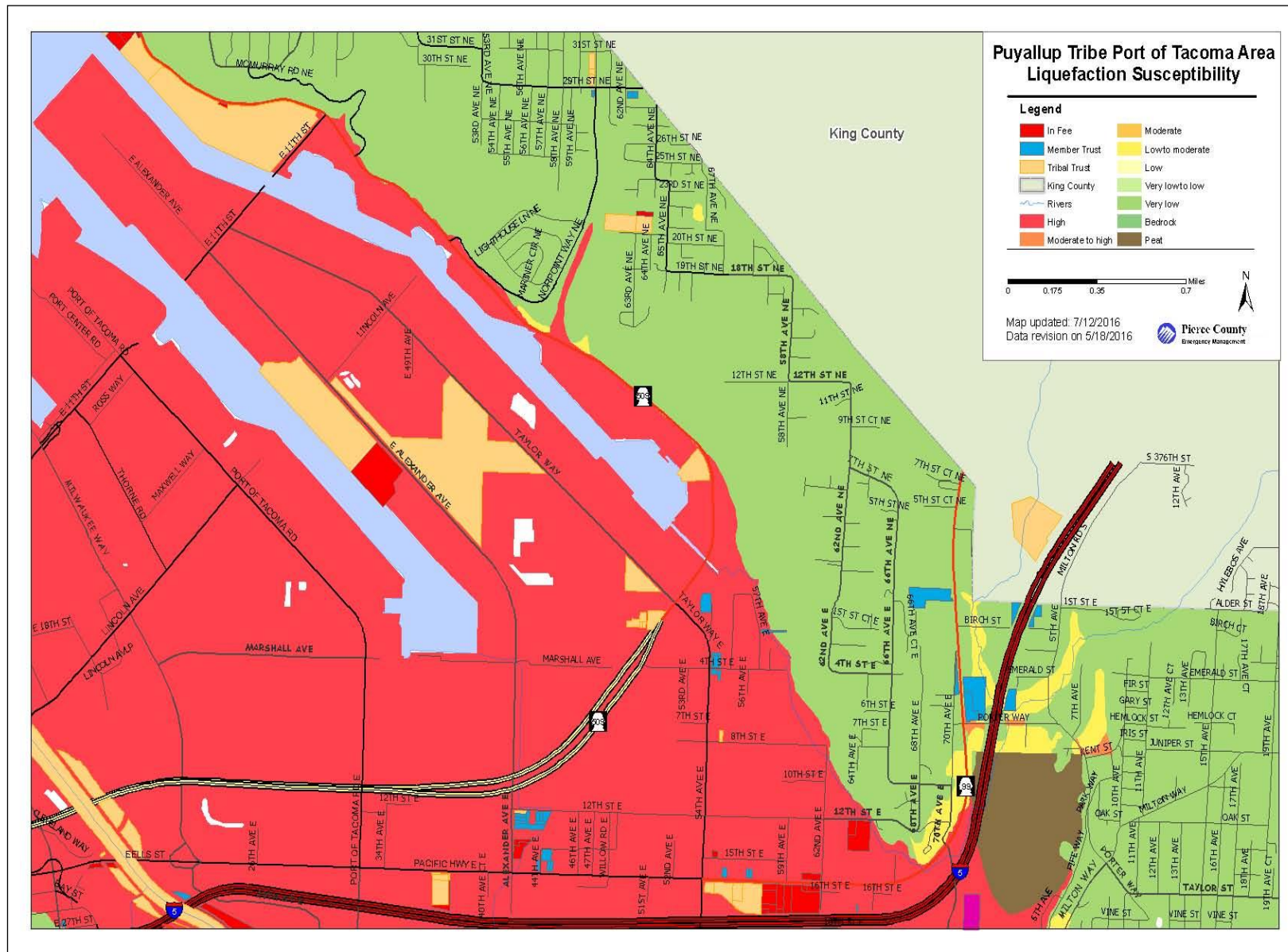
PUYALLUP TRIBE SEISMIC HAZARD AREA



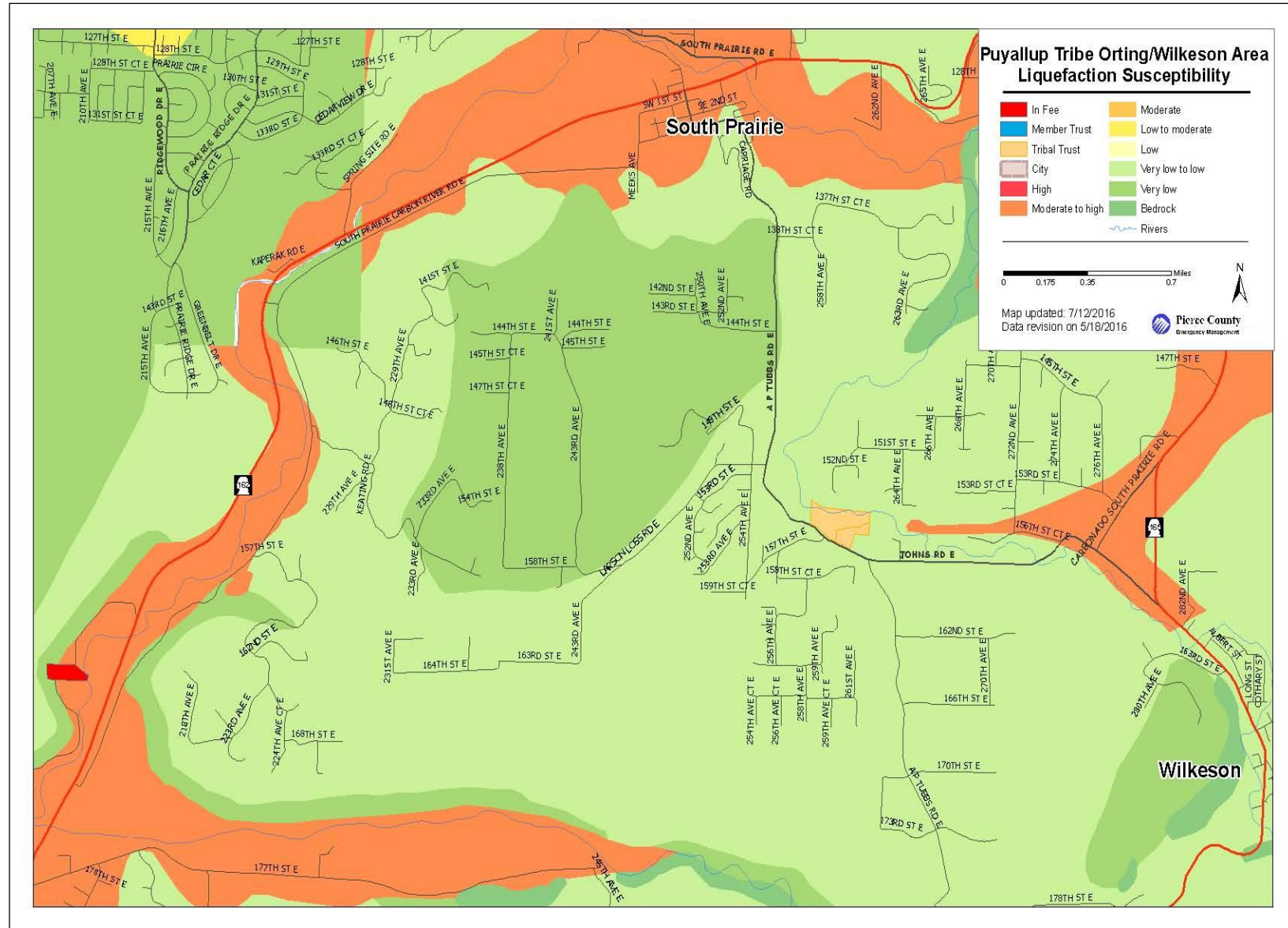
Map 4.2-6 Puyallup Tribe of Indians Fife/Puyallup Liquefaction Susceptibility



Map 4.2-7 Puyallup Tribe of Indians Port of Tacoma Liquefaction Susceptibility



Map 4.2-8 Puyallup Tribe of Indians Orting/Wilkeson Liquefaction Susceptibility



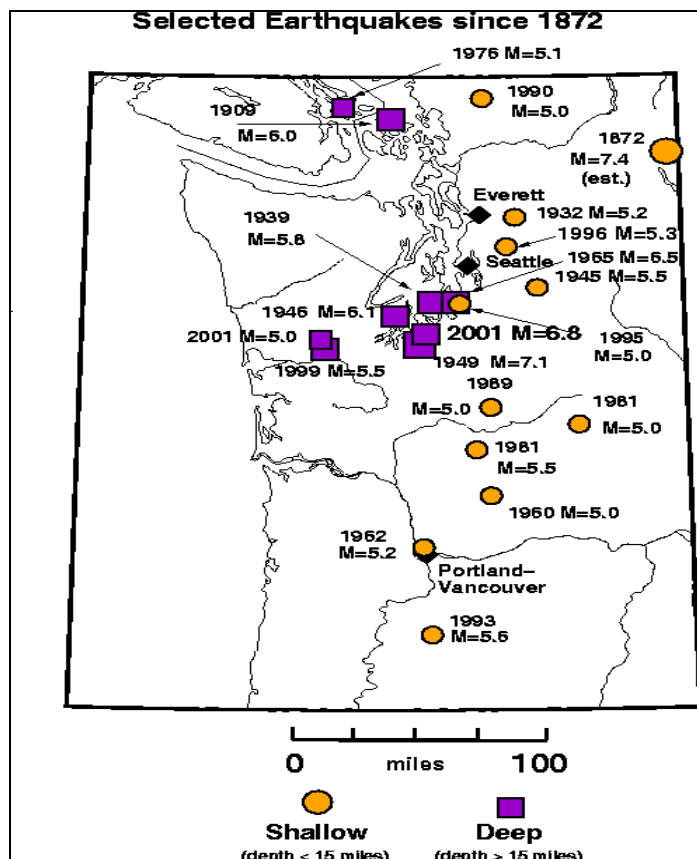
Pierce County are located in the County's river valleys. The largest area of liquefiable soils is the Puyallup River Valley while the Carbon, White, and Nisqually River Valleys are also liquefaction hazard areas. The areas with the highest liquefaction hazard are located in both incorporated and unincorporated areas of the County. Auburn, Buckley, Eatonville, Fife, Milton, Puyallup, Orting, South Prairie, Sumner, and Tacoma all have at least some of their land located in these areas.

Map 4.2-4 illustrates the location and extent of the Puyallup Tribe Reservation's seismic hazard based on areas of liquefaction. With the majority of the Reservation located along the Puyallup River valley the risk for liquefaction is extremely high. Many of the Tribe's Trust Lands are located within these areas. Map 4.2-5 through Map 4.2-8 allows for a detailed identification of specific Tribal Trust Lands and their vulnerability to liquefaction. This will allow the Puyallup Tribe to easily identify which buildings are at the highest risk for mitigation efforts or knowledge of at highest risk areas for future construction.

The other area of earthquake risk is in the area of landslide potential. Earthquakes tend to create landslides as a secondary hazard. This can be especially true during periods when the soils are saturated. In Pierce County this can go from October through June depending on the fall and winter weather. The landslide potential can be seen in the Landslide section on maps 4.3-1, 4.3-2 and 4.3-3.

Occurrences⁷

Map 4.2--9 Major Pacific Northwest Earthquakes¹



Over the last 100 years, a large area of the state has experienced earthquake damage. The majority of the largest earthquakes felt in Washington have occurred in the Puget Sound region between Olympia and the Canadian border, in the Cascade Mountains, and along the Washington-Oregon border. Medium to large magnitude earthquakes (greater than 5.0) have occurred repeatedly in the Puget Sound region. Map 4.2-9 shows the location, date, and magnitude of major earthquakes since 1872 in the Pacific Northwest.

In addition Table 4.2-1 lists some of the notable earthquakes felt in Pierce County and is followed by a discussion of occurrences by type of earthquake.

Intraplate (Benioff Zone⁸) Earthquakes⁹

The magnitude 6.8 Nisqually earthquake on February 28, 2001 caused extensive non-structural damage throughout the region. Although estimates are still being totaled, to date losses from this event are greater than \$350 million statewide. The large earthquakes of 1965 (magnitude 6.5), 1949 (magnitude 7.1), and 1946 (magnitude 6.3) killed 17 people and caused more than \$340 million (2002 dollars) in property damage in several counties. Since 1870 there have been six significant intraplate earthquakes in the Puget Sound basin.¹⁰ Based on the historical record we can say that the actual recurrence rate of events this size is about every 23 years.

Table 4.2-1 Notable Earthquakes, Magnitude 5.0 or Greater, Felt in Pierce County¹¹,

DATE YY/MM/DD	(UTC)TIME HH:MM:SS	LATITUDE (N)	LONGITUDE (W)	DEPTH (KM)	MAG	COMMENTS
1872/12/15	05:40:00	47.75N	119.87W	0.0	6.8	14.5 KM SE OF CHELAN, WA
1880/12/12	20:40:00	47.50N	122.50W	0.0	6.0	12.3 KM SE OF BREMERTON, WA
1882/04/30	10:40:00	47.40N	122.59W	0.0	5.7	18.7 KM S OF BREMERTON, WA
1891/03/07	07:40:00	47.50N	121.75W	0.0	5.0	2.7 KM E OF NORTH BEND, WA
1891/11/29	23:21:00	48.00N	123.50W	0.0	5.6	13.5 KM SSW OF PORT ANGELES, WA
1904/03/17	04:20:00	47.79N	123.00W	0.0	5.3	27.6 KM WNW OF POULSBO, WA
1931/12/31	15:25:00	47.50N	123.00W	0.0	5.0	28.9 KM WSW OF BREMERTON, WA
1932/07/18	06:01:00	48.00N	121.80W	0.0	5.7	15.6 KM SE OF GRANITE FALLS, WA
1932/08/06	22:16:00	47.70N	122.30W	0.0	5.0	7.2 KM WNW OF KIRKLAND, WA
1939/11/13	07:45:54	47.40N	122.59W	31.0	6.2	18.7 KM S OF BREMERTON, WA
1945/04/29	20:16:17	47.40N	121.69W	0.0	5.7	12.5 KM SSE OF NORTH BEND, WA
1945/04/30	07:45:45	47.40N	121.69W	0.0	5.0	12.5 KM SSE OF NORTH BEND, WA
1946/02/15	03:17:47	47.29N	122.90W	25.0	5.8	28.4 KM N OF OLYMPIA, WA
1946/02/15	12:17:15	46.86N	122.26W	0.0	5.0	0.3 KM NW OF EATONVILLE, WA
1946/02/23	08:54:53	47.04N	122.88W	0.0	5.0	0.0 KM SE OF OLYMPIA, WA
1946/06/23	15:13:00	49.80N	125.30W	0.0	7.4	26.3 KM WNW OF COURTENAY, BC
1948/09/24	22:35:00	47.85N	122.58W	0.0	5.0	14.0 KM NNE OF POULSBO, WA
1949/04/13	19:55:43	47.09N	122.75W	54.0	7.1	12.3 KM ENE OF OLYMPIA, WA
1954/05/15	13:02:32	47.40N	122.50W	0.0	5.0	18.9 KM NNW OF TACOMA, WA
1965/04/29	15:28:43	47.40N	122.40W	57.0	6.5	18.3 KM N OF TACOMA, WA
1980/05/18	15:32:11	46.20N	122.18W	2.8	5.7	1.0 KM NNE OF MT ST HELENS, WA
1981/02/14	06:09:27	46.34N	122.23W	7.3	5.2	1.8 KM N OF ELK LAKE, WA
1981/05/28	09:10:45	46.52N	121.39W	3.2	5.0	4.4 KM ENE OF GOAT ROCKS, WA
1990/04/14	05:33:26	48.84N	122.16W	12.6	5.0	4.7 KM ENE OF DEMING, WA
1995/01/29	03:11:22	47.38N	122.36W	15.8	5.0	17.5 KM NNE OF TACOMA, WA
1996/05/03	04:04:22	47.76N	121.87W	4.3	5.4	8.5 KM ENE OF DUVALL, WA
1999/07/03	01:43:54	47.07N	123.46W	40.7	5.8	8.0 KM N OF SATSOP, WA

DATE YY/MM/DD	(UTC)TIME HH:MM:SS	LATITUDE (N)	LONGITUDE (W)	DEPTH (KM)	MAG	COMMENTS
2001/02/28	18:54:32	47.14N	122.72W	51.9	6.8	17.0 KM NE OF OLYMPIA, WA 1361-DR-
2001/06/10	13:19:11	47.16N	123.50W	40.7	5.0	18.3 KM N OF SATSOP, WA

Crustal Earthquakes¹²

Best available science indicates that on the Tacoma Fault uplift to the north and subsidence to the south occurred most recently in A.D. 800–1200, not necessarily in a single year. The age range of this uplift on the north side of the Tacoma Fault includes times of co-seismic uplift and subsidence at many sites around Puget Sound. The lack of estimates for the Tacoma Fault reflects an early stage of research into the Holocene history of this structure.¹³ It must be understood that damage could also come from earthquakes on other crustal faults from both within and outside Pierce County. Of particular concern are the Seattle Fault and the West Rainier Seismic Zone. Other small localized faults like the Burnett, Wilkeson, Miller and Devereaux faults in the eastern portion of the County might cause some localized problems but are not expected to cause widespread damage. There is always the possibility that an undiscovered fault underlying the glacial till that covers much of the County that could cause a damaging earthquake.

Cascade Subduction Zone Earthquakes¹⁴

In addition to crustal and intraplate earthquakes, research indicates that the subducting Juan de Fuca Plate has generated great earthquakes. These earthquakes estimated to be in the range of magnitude 8 to 9 appear to have occurred at uneven intervals over the past several thousand years. At least 13 great subduction earthquakes may have occurred in the Pacific Northwest over the past 7,000 years. The most recent great subduction earthquake in Washington State occurred over 300 years ago on January 26, 1700. At this time it appears that the mean recurrence rate is about 550 years. The actual recurrence rate is highly variable with the shortest time period between them being around 100 years, and the longest time span being around 1,100 years.¹⁵

For each of these sources, the largest earthquakes recur at poorly known, probably irregular, intervals. On average, the intervals are on the order of decades for the intraplate earthquakes on the Juan de Fuca Plate, millennia for the best-known of the upper-plate faults (the Seattle Fault), and centuries for the plate boundary.

Recurrence Rate

Although the earthquake record in Washington State is relatively short to form precise estimates of the recurrence rate for earthquakes, the record we do have allows at least an estimate of the overall rate. Realizing the fact that earthquakes happen daily in Washington, we are only interested in the ones that potentially cause damage. Taking into account the three different types of earthquakes listed above and the past occurrences we know of, we find that for the short historical record we have the intraplate earthquakes are the ones with by far the shortest recurrence rate. It must be realized that the 36 year period between the 1965 quake and the 2001 earthquake may be closer to the real average and that the 23 year average from the record may be a little short. So until better scientific evidence allows an improved estimate of the actual

recurrence rate we will list the probability of recurrence for the earthquake hazard in the Planning Area and Pierce County to be less than 40 years.

Vulnerability

While the entire County experiences shaking during earthquakes, areas of liquefaction experience even greater shaking. Map 4.2-4 illustrates the location and extent of the Planning Area's seismic hazard based on areas of liquefaction. As illustrated on Map 4.2-3, the majority of liquefiable soils are located in the River Valleys. The largest area of liquefiable soils is the Puyallup River Valley while the Carbon, White, and Nisqually River Valleys are also liquefaction hazard areas. The areas with the highest liquefaction hazard are located in both incorporated and unincorporated areas of the County. Auburn, Buckley, Eatonville, Fife, Milton, Puyallup, Orting, South Prairie, Sumner, and Tacoma all have at least some of their land located in these areas including the Planning area.

Because of their nature, earthquakes impact the entire Planning Area. Some parts of the Planning Area are more at risk than others because of the presence of liquefiable soils. As shown on Map 4.2-4, approximately 50% of the developed land is on these areas of greater risk. The majority of high seismic risk is located within the river valleys, where the liquefaction risk is high and completely covers the valley floor. There are some small pockets of land that are prone to dynamic settlements, as well as a larger area near the northeast corner of the Planning Area.

Some of the ridges along the river valley may be vulnerable to earthquake-induced landslides, especially as more development occurs along the hillside. Earthquakes tend to create landslides as a secondary hazard. This can be especially true during periods when the soils are saturated. In Pierce County this can go from October through June depending on the fall and winter weather. The landslide potential can be seen in the Landslide section on maps 4.3-1 and 4.3-2.

Finally, areas near the northwest of the Puyallup River and the Port of Tacoma (Commencement Bay) area susceptible to earthquake induced underwater landslides or delta failures (for more on the vulnerability, see Sub-Section 4.4, Tsunami's).

Planning Area

The Planning Team determined that Planning Area has a medium vulnerability to the earthquake hazard because of the following factors: probability of recurrence, the Area's proximity to faults, the predominant presence of soft soils, and the age and type of structures. The areas noted above as being at risk to liquefaction and dynamic settlement increase the vulnerability for structures, infrastructure, and resources located there. The hillsides that comprise the valley walls may be vulnerable to landslides, especially as they continue to develop.

In the entire Planning Area, over 18,000 acres are vulnerable to earthquakes and earthquake-induced events. The total damage to the Planning Area could exceed \$8 billion (the assessed value of all parcels in the Planning Area).

A more detailed vulnerability assessment by the Planning Team showed that approximately 9,068 acres (50% of the Planning Area) are located in areas of moderate to high liquefaction making those acres even more vulnerable to the earthquake hazard. The total estimated losses to

these parcels would equal \$4 billion. See maps 4.2-5 to 4.2-8 for detailed liquefaction potential to Tribal Trust properties.

For Tribal Trust parcels located in the Planning Area, all 485 parcels are vulnerable to earthquake hazard. The total estimated losses to these parcels would equal \$300 million.

Of the 485 Tribal Trust parcels in the Planning Area, 162 parcels (33.4%) are located in areas of moderate to high liquefaction. The total estimated losses to these parcels would equal \$232 million.

Impacts

All discussion of the impacts of an earthquake has to take into account the magnitude, epicenter and focus of the earthquake. This includes whether it is a subduction quake on the junction of the Juan de Fuca and North American plates off the coast of Washington, a deep earthquake like the 2001 Nisqually quake or one on either the Seattle or Tacoma faults. Other variables outside the obvious impact of magnitude of the quake include weather both before and after the earthquake, the time of day, time of year, and the percentage of older buildings of construction techniques that are not up to current building code standards. For the purposes of this section, preliminary impacts will be from the Scenario for a Magnitude 6.7 Earthquake on the Seattle Fault.¹⁶

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

Depending on the size and location of the earthquake the affect on persons in the impacted area is expected to range from a repeat of the Nisqually quake of 2001 up to those from a hypothetical 6.7 or larger earthquake on one of the major faults in Puget Sound or a large subduction quake located off the coast of Washington.

The magnitude 6.8 Nisqually Earthquake of February 28, 2001 resulted in one death and approximately 400 recorded injuries, including a dozen that were serious, throughout the Puget Sound Basin.¹⁷ The expectation is that similar quake would produce similar results. The affects of a surface rupture on the Seattle or Tacoma faults could lead to a much greater loss of life and injuries. Losses are estimated to be equivalent to those from the Northridge California quake of 1994. However, in Northridge, the time of day dramatically decreased the actual number of casualties. That earthquake, striking at 4:30 in the morning, did not cause the number of deaths and injuries that would have happened at a later hour. At that time the number of people on the roads and bridges that collapsed was very low as were the staff in the buildings that collapsed. In contrast estimated losses here in the Puget Sound Basin are expected to top 1,600 fatalities and 24,000 injuries.¹⁸ These estimates are based on one distinct scenario, a 6.7 earthquake on the Seattle Fault. A variation on this either up or down in the magnitude could have a significant effect on the outcome.

In discussing a subduction quake, it must be understood that while the State has experienced quakes of this type possibly as high as magnitude 9, all of them were prior to settlers with a written language entering the State of Washington. The violent shaking expected with a surface quake on the Tacoma or Seattle faults will be attenuated to a certain extent by the distance from the actual fracture zone. Located off the Washington coast, the earthquake waves will have to

travel over 100 miles to reach Pierce County. On the other hand “(T)his particular type of earthquake is especially hazardous to tall buildings, which could lead to significant fatalities in downtown areas.”¹⁹

In previous large earthquakes the potential for an outbreak of disease appears to increase. This can be caused by polluted water sources, the eating of spoiled food, and the inhalation of dust kicked up by the quake. In addition here in Pierce County there could be environmental injuries such as hypothermia if the earthquake happened during the winter months.

Figure 4.2-2 Salmon Beach, Tacoma Washington – Following Feb. 2001 Earthquake



Health and Safety of Personnel Responding to the Incident

Responders are subject to a number of hazards in the response phase of the emergency. Damaged fire stations could prevent fire personnel from utilizing all the equipment with which they are used to responding. Already damaged structures could collapse during search and rescue operations, especially during aftershocks. Response personnel, by the very nature of their work are putting themselves in harm's way, not just from structural collapse during aftershocks but also from further landslide activity and respiratory problems due to the inhaling of quantities of dust and microbes stirred up by the earthquake. In addition they can be exposed to bacteria and chemicals in the environment they are working in, sometimes without realizing what the particular dangers are. “Following the Loma Prieta earthquake, about 20% of post-earthquake injuries were caused by toxic materials.”²⁰ For those who are caught in the dust cloud created by an earthquake the respiratory problems could be similar to those experienced by first responders to the World Trade Center collapse in 2001.²¹ This can be shown to be a problem across many different emergency responses. It correlates with the amount of toxins and dust that are in the

environment, for example approximately 80% of Red Cross responders who went to work on Hurricane Katrina response returned home with respiratory infections.²²

First responders frequently have adverse psychological reactions to trauma and especially disasters. Long term psychological impacts were noticed years ago, such as after the collapse of the Hyatt Regency Hotel walkway in Kansas City, Missouri in 1981, and eventually led to the development of Critical Incident Stress Management. Divorce and suicide rates are higher than the norm“(S)tress is not like a light switch—the images of such tragic events often haunt the responder into his or her home life, piling more pressure on other events. Ill health effects can include high blood pressure, sleep disorders, alcohol or sleeping aid abuse, anger, withdrawal from family members, over protectiveness for family members, and even paranoia.”^{23, 24}

Continuity of Operations and Delivery of Services

For a large earthquake impacting Pierce County, continuity of operations will be severely taxed for many, if not most, of the agencies and jurisdictions located therein. The impacts affecting continuity of operations include:

- Death or injury to staff limiting the number of staff able to fill normal operational duties;
- Inability of staff to respond to their work sites due to road closures from debris on the roads, liquefaction or lateral spreading damaging the roads, and bridges or overpasses damaged closing arterials in particular;
- Staff absenteeism while checking on or taking care of family, and handling damage to home or other personal property;
- Damage to communications systems will limit organizations’ ability to coordinate their own resources, and it will also limit their ability to pull together a full picture of the damage suffered in their jurisdiction and to request assistance if needed
- Damage to facilities and equipment; and
- Damage to the water, energy and sewer systems connected to agency facilities will not allow operations to continue in their normal manner.

Due to the limitations mentioned above, delivery of services will be heavily impacted by a large earthquake. Infrastructure damage or destruction combined with lack of staff will retard delivery of normal governmental services.

Law enforcement operations will be taxed to the maximum. Road closures, prevention of citizens entering hazardous areas, control of looting, responding to search and rescue operations, etc. combined with a decrease in available staff due to all the factors listed above will severely limit normal day-to-day operations. Most individual law enforcement officers operate independently of others in their jurisdiction. Since many of them have their equipment with them, including cars, they may be able to assist at least in the area they are at when the earthquake happens. Fire response will be impacted in a similar vein, however for many of them they will have to report to a station where they can respond from. Between the inability to get to their station and the possibility that the stations and equipment may be damaged or destroyed the response will be compromised. Many fire stations, especially the older ones, even though they have survived previous moderate quakes may not survive a large one. Even if a station is not destroyed or collapsed, a racking of the walls could jam the bay doors closed.

Public works and utilities will not have the ability to have services back up and operational, in many cases, for days, weeks or even months. Repair of roads, bridges, water and sewer lines, the electric grid and telephone lines and towers will tax these utilities to the maximum. Even with the importation of mutual aid and other assistance from other portions of the state and other states, the service delivery will be slow to develop and spotty at best for some time.

Schools will be unable to fulfill normal expectations. Damage to schools' infrastructure as well as the public infrastructure of roads and utilities will close down schools at least temporarily. Those that might be able to be operational will, in many cases, have to act as temporary shelters for those displaced by the earthquake. Immediately after the earthquake if school is in session they may have to house students for days until parents are able to retrieve them.

Property, Facilities, and Infrastructure

Any large earthquake on the Seattle or Tacoma Faults or from many other faults in Washington State will create damage to the property, facilities and infrastructure either owned by jurisdictions in Pierce County or needed to support their economy and citizens. This includes damage to buildings, electrical grids, telephone service, including cell operations, water and sewer utilities, port facilities, transportation systems, and both natural gas and liquid fuel pipelines.

A number of factors will determine the effect of ground shaking on the building stock and infrastructure of any area. These include: soil composition, age of the facilities, focus (depth of the quake) or, epicenter (point on the earth's surface directly over the focus), weather previous to the event surface faulting subsidence and uplift.

First is soil composition. Soft and liquefiable soils will both intensify ground shaking and in the case of liquefiable soils lose structural integrity. Earthquake waves moving along the surface of the ground have different characteristics depending on the soil composition they encounter. These surface waves, when they progress from one soil type to another change. They tend to travel slower through soft soils than they do through hard soils or bedrock. Yet the energy contained in the wave stays the same. The result is that as the wave changes speed the amplitude will change in relation to it, increasing in soft soils and decreasing in hard soils. This increase in wave amplitude in soft soils can damage structures, especially unreinforced masonry and pre-1970 tilt up structures.²⁵

When the soil loses structural integrity, liquefaction or lateral spreading may be the result. This is especially prevalent in areas of artificial fill like on the Tacoma Tide Flats and the valley bottoms like the Puyallup and Nisqually where thousands of years of silt and sand washing down the river combined with lahar debris has created soils prone to it. In cases like this, buildings or portions of buildings built on it may sink; see *Figure 4.2-3 Liquefaction, Niigata Japan, 1964*.²⁶

In the case of lateral spreading, it can move railroad tracks, bend or collapse roads, move cranes or do other damage associated with the soil under the facility moving, see *Figure 4.2-4 Lateral spreading along North Deschutes Parkway in Thurston County*.²⁷ This damage, while in many cases not as spectacular looking as buildings tipped over by liquefaction, can have a major impact on the community. For emergency operations it limits the ability of emergency workers to respond to incidents throughout the community and it can prevent people from bringing the

community back to normal and developing its economic base until this portion of the infrastructure has been repaired.

Secondly, much of the building stock that exists in Pierce County was built before current earthquake codes were put into place and before there was much of an understanding of the actual hazard that exists from earthquakes in Washington State. It was only towards the end of the 1980s that geologists began to understand some of the processes that cause earthquakes in the Pacific Northwest. Since that time both geologic research into our local earthquake hazard as well as engineering studies of building response in earthquakes has shown that some of the older building stock could have major structural problems, possibly to the point of collapse. The third and fourth factors that will have a major bearing on the damage done to a community and to its ability to recoup from its losses

are the depth of the earthquake (focus) and the location of its epicenter in relation to the rest of the County.

An intraplate earthquake located inside the Juan de Fuca Plate as it dives under the North American Plate will be deep enough that the waves it generates will be attenuated or lose some energy as they propagate outwards from the focus. In such a situation, even if the earthquake's epicenter is located in Pierce County the damage will not be too catastrophic. This was the case with the 2001, 1965 and 1949 earthquakes all of which had epicenters close to or in Pierce County, see *Table 4.2-1 Notable Earthquakes Magnitude 5.0 or Greater Felt in Pierce County*.

Taking the same size earthquakes, with magnitudes 6.8, 6.5, and 7.1 respectively, and moving them close to the surface could have caused damage similar to the Northridge, California (6.7), Loma Prieta, California, (7.1), or Kobe, Japan (6.8) earthquakes. In each of these cases with the epicenter of the quake, 2001 (Anderson

Island), 1965 (Des Moines) and 1949 (Nisqually Delta), deaths and injuries would have been much more prevalent. Buildings would have collapsed, fires would have started, bridges and freeway overpasses would have been more heavily damaged and other lifelines would have been in disarray or out of commission for long periods of time.

This is the scenario that Pierce County is looking at if there was an earthquake of that size on the Tacoma Fault. In addition, any

Figure 4.2-3 Liquefaction, Niigata Japan 1964



Figure 4.2-4 Lateral Spreading –March 2001



earthquake on a surface fault close to Pierce County like the Seattle or Olympia faults will cause damage in Pierce County although probably to a lesser degree, being some distance away. A subduction zone earthquake will be located further away from Pierce County than the surface quakes mentioned above and so the waves will be attenuated somewhat by the time they get to Pierce County compared to their size on the coast. However the shaking could run for multiple minutes. This shaking could continue for a much longer time than the intraplate earthquakes we have historically had. While all of Pierce County is vulnerable to this type of earthquake, the most vulnerable areas will be those containing soft soils, both natural and those created by artificial fill.

The next factor that can influence the outcome of an earthquake is the weather. The weather previous to the earthquake will have an affect on the eventual outcome. Rain saturating the ground can increase both the potential for earthquake generated landslides and the probability that liquefaction or lateral spreading will occur. This could increase the probability that pipes could break. Lateral spreading under roads, railroad tracks and port facilities would increase disrupting transportation and there could be an increase to building damage due to liquefaction. The other area that could cause damage is actual surface disruption either from surface faulting, or subsidence and uplift. Fault ruptures breaking the surface can rip buildings apart, destroy bridges, offset roads, break pipelines, destroy sewer lines, and stretch or break transmission lines. The same can be said for subsidence and uplift. Having a building, road or any other piece of infrastructure where a portion of it either rises or falls in relation to the rest will break or destroy it. Actually any piece of infrastructure either in the ground or on its surface can be broken or destroyed by any of these three effects.

Changes in the ground can affect the water table. Wells may change their water levels or go dry. Stream flows may be altered and on a macro scale landslides or other ground deformation may change the course of streams or rivers.

The Environment

Impacts, or damage, to the environment may be thought of as two different processes. There is direct change to the environment caused by the earthquake. This incorporates all the natural damages such as landslides, coastal uplift, inundation of low lying areas with coastal subsidence and tsunami damage. In contrast the other process involves the pollution that becomes endemic in the aftermath of an earthquake that strikes an urban area or some part of the infrastructure today.

Concerning traditional environmental changes due to earthquakes, while many times damaging in the short term, many of the changes caused by them are overcome with time as the local ecosystem absorbs them. These types of environmental effects have been happening for as long as the land that is now Pierce County has been around. These types of impacts include:

- Landslides will sometimes block streams or rivers forcing them to reroute, occasionally causing lakes that swamp the local vegetation leaving a ghost forest standing in the water. Landslides can increase erosion affecting fish habitats. They can cause tsunamis that can damage coastlines.
- Coastal uplift raises sections of the near shore marine environment above the tide line, killing all near shore tidal life in the area raised above the tide line.
- Coastal subsidence dropping areas of beach and near beach land so that water now covers land that was recently dry. This can drown plants and animals in newly submerged areas and in some areas lead to saltwater intrusion into the local ground water supply.

- Tsunamis causing local erosion of the beaches, direct damage to plants and animals living on the beach, and possible saltwater damage to non-salt tolerant species away from the beach.

Today, however, there is another type of environmental damage that is the result of human intervention. That is the damage caused by the release of hazardous chemicals and/or large quantities of sewage. These can be released from many different sources including but not limited to industrial plants, pipelines, overturned trucks, damaged ships or barges, railcars and even school chemistry labs. These impacts to the environment include:

- Air pollution: some chemicals released as gasses can cause immediate damage to plants, animals and humans. Tanks filled with, for example, chlorine, ammonia or any other hazardous gas can harm or kill animals, birds, and plants, not just in the area of the spill but for some distance downwind depending on the chemical involved and the size of the release. The damage will usually be temporary and physical recovery to the environment will begin as soon as the gas dissipates.
- Chemicals that spill either directly into or that have the ability to drain into lakes, ponds, streams, rivers, or even drainage ditches could kill or create birth defects in fish and marine mammals. In some areas they would pollute drinking water. Depending on the chemicals involved and their ability to be either absorbed by the environment, or break down quickly the environment may either recuperate quickly or be impacted for years or even decades. Damage to port facilities could create spills into the waterways that tidal currents could spread throughout the coastal areas of Puget Sound causing damage into Kitsap, King, Pierce, and Thurston Counties.
- Damage to wastewater treatment facilities, sewers, pump stations, etc. could lead to spills of sewage or the inability of the treatment plant to process waste allowing it to flow untreated into the local environment. This would have the same effect as many other hazardous chemicals, polluting the environment for possibly weeks, but also creating conditions that could with bacterial contamination lead to disease in both animals and humans.
- Spills onto land can, depending again on the type of chemical, either temporarily, as with the case with many caustics or acids or permanently, as with spills of heavy metals or many radioactive materials damage soils. Related to this is the absorption of material by the soil may allow it to pollute groundwater and be transferred for some distance causing damage. Depending on the ability of water and the chemical to leach through the underlying layers of soil, clay, rock, etc. it could eventually reach and pollute the aquifer.

Economic and Financial Condition

The economic effects from a large damaging earthquake will be extensive and the overall financial condition of most businesses, as well as local governments in Pierce County, will be compromised.

Economic factors will be impacted first by the direct damage to homes, businesses and the infrastructure. A number of factors come into play here. First, the housing stock will be affected, and while some people have earthquake insurance, the majority does not. Most home construction built to contemporary earthquake standards will probably not collapse, however damage could be extensive to older structures especially those not connected to their foundations. While assistance from FEMA and SBA will help with reconstruction, there could still be a large gap in what is needed to get families back into their homes.

Looking at the results of other earthquakes both in the Pacific Northwest and California, it can be seen that many businesses' building stock will be damaged. This will be especially prevalent in the areas of soft soils and older building stock. Combining this with the loss of water, electricity, and natural gas means that much of the local industry and businesses will not be able to continue operations in their normal manner. Most will be closed for at least a nominal portion of time. This will mean lost wages. In an escalating sequence of events the wage earner will not be able to buy necessities or pay bills that come due, including mortgages. This can lead to foreclosures and the further displacement of the population.

The loss of the transportation corridors including roads, rail transport and the damage to the Port of Tacoma will make it nearly impossible to both import needed supplies and to ship goods to market in the near term. Some of these facilities may take years to recover.

Other economic factors impacting businesses include loss of inventory, or for those businesses that operate on a "just in time" re-supply schedule and do not have an inventory, the loss of their ability to be re-supplied may denote the end of their business.

A contributing factor includes the inability of staff to report to their work. This will be due in some cases to injury, while for others they could be looking after their own homes and families. Another factor leading to staff absenteeism is the damage done to the transportation corridors.

The damage to homes, industry and other businesses will also have a direct impact on the long term operation of government and the public infrastructure. With the loss of a percentage of the tax base due to damage, and the exorbitant cost of bringing the infrastructure back to normal, there will not be funds available for many of the services that citizens have grown to expect. This will have a compounding effect of not attracting other business to the County which then continues to limit the tax base.

Public Confidence in the Jurisdiction's Governance

How the after effects of the earthquake are handled will have a great deal to do with the public's confidence in the jurisdiction. For smaller size quakes there should be little or no decrease in the public's confidence about government's ability to act. However, as the size of the earthquake increases and as the parameters that could lead to major damage increase, such as depth, epicenter, rainy weather, etc., then the possibility of the public finding fault with local jurisdictions or agencies increases.

Local agencies and governments must be able to respond quickly to revive any portions of the infrastructure that have been impacted by the earthquake. The longer the delay in service restoration, the more the public loses confidence in an agency's or government's ability to handle the situation. Since many of the long term effects of an earthquake have social and economic consequences, the more the public perceives that government is ignoring their plight or unable to respond to it, the more the public will lose confidence in it. Eventually, any perceived lack of ability, or slow response will result in finger pointing and acrimony.

Resource Directory

Regional

- **Pierce County Department of Emergency Management**
<http://www.co.pierce.wa.us/PC/Abtus/ourorg/dem/abtusdem.htm>
- **Pacific Northwest Seismograph Network**
<http://www.geophys.washington.edu/SEIS/PNSN/welcome.html>
- **Washington State Emergency Management Division**
http://www.emd.wa.gov/hazards/haz_earthquakes.shtml
- **Washington State Department of Natural Resources**
<http://www.dnr.wa.gov/>
- **Pacific Northwest Seismograph Network: Research in Seismology, Tectonics, and Engineering**
<http://www.pnsn.org/RESEARCH/welcome.html>

National

- **Building Seismic Safety Council**
<http://www.bssconline.org>
- **California Division of Mines and Geology**
<http://www.consrv.ca.gov/cgs/>
- **Earthquake hazard history, by state**
<http://wwwneic.cr.usgs.gov/neis/states/states.html>
- **Earthquake maps and information**
<http://www.abag.ca.gov/bayarea/4.1maps/4.1maps.html>
- **FEMA HAZUS homepage**
<http://www.fema.gov/plan/prevent/hazus/index.shtm>
- **GIS data available on earthquakes**
<http://earthquake.usgs.gov/research/hazmaps/>
- **USGS Earthquake homepage**
<http://quake.wr.usgs.gov/>

- **USGS Earthquake Hazards Program**
<http://www.earthquake.usgs.gov>
- **USGS National and regional custom earthquake risk maps**
<http://earthquake.usgs.gov/research/hazmaps/interactive/index.php>
<http://www.usgs.gov/hazards/>

Endnotes

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

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

² *Ibid.*, p. 3-4.

³ USGS publication. "Earthquake Hazards in Washington and Oregon, Three Source Zones."

<http://www.ess.washington.edu/SEIS/PNSN/CascadiaEQs.pdf>

⁴ A pending US Geological Survey publication.

⁵ Gonzalez, Frank I., et al. "Puget Sound Tsunami Sources: 2002 Workshop Report." NOAA/Pacific Marine Environmental Laboratory, Contribution No. 2526, 2003. p. 7.

⁶ *Ibid.* p. 7.

⁷ Modified from PC HIVA (DRAFT), Earthquake Section, September 5, 2002, p. 2.

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

⁸ "A dipping planar (flat) zone of earthquakes that is produced by the interaction of a downgoing oceanic crustal plate with a continental plate. These earthquakes can be produced by slip along the subduction thrust fault or by slip on faults within the downgrading plate as a result of bending and extension as the plate is pulled into the mantle. Also known as the Wadati-Benioff zone." From the USGS Earthquake Glossary at <http://earthquake.usgs.gov/learn/glossary/?term=Benioff%20zone>

⁹ *Ibid.* p. 2-3.

¹⁰ Earthquakes in Washington, Walsh, Timothy J., et. al., Washington State Department of Natural Resources, Division of Geology and Earth Resources,

www.dnr.wa.gov/ResearchScience/Topics/GeologicHazardsMapping/Pages/earthquakes.aspx

¹¹ http://www.pnsn.org/HIST_CAT/isoseismals.html

http://www.pnsn.org/HIST_CAT/CASCAT2006/Index_84_151.html

http://www.pnsn.org/HIST_CAT/CASCAT2006/Index_152_216.html

http://www.pnsn.org/HIST_CAT/CASCAT2006/Index_217_327.html

http://www.pnsn.org/HIST_CAT/CASCAT2006/Index_328_430.html

http://www.pnsn.org/HIST_CAT/CASCAT2006/Index_431_535.html

http://www.pnsn.org/HIST_CAT/CASCAT2006/Index_536_674.html

http://www.pnsn.org/HIST_CAT/CASCAT2006/Index_675_677.html

¹² Gonzalez, Frank I., et al. "Puget Sound Tsunami Sources: 2002 Workshop Report." NOAA/Pacific Marine Environmental Laboratory, Contribution No. 2526, 2003. p. 7-8.

¹³ An earthquake raised shorelines along the Seattle Fault Zone in A.D. 900–930; moreover, several shores of southern Puget Sound subsided A.D. 860–940. Therefore, the uplift north of the Tacoma Fault either coincided with a single large event in A.D. 900–930, or it represents a separate earthquake of about that age. However, the subsidence at Wollochet Bay on the peninsula in Pierce County implies either co-seismic or a seismic deformation after A.D. 900–930. Gonzalez, Frank I., et al. "Puget Sound Tsunami Sources: 2002 Workshop Report." NOAA/Pacific Marine Environmental Laboratory, Contribution No. 2526, 2003. p.4.

¹⁴ Modified from PC HIVA (DRAFT), Earthquake Section. September 5, 2002, p. 3-5.

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

¹⁵ Earthquakes in Washington, Walsh, Timothy J., et. al., Washington State Department of Natural Resources, Division of Geology and Earth Resources,

www.dnr.wa.gov/ResearchScience/Topics/GeologicHazardsMapping/Pages/earthquakes.aspx

¹⁶ Scenario for a Magnitude 6.7 Earthquake on the Seattle Fault, Earthquake Engineering Research Institute and the Washington Military Department, Emergency Management Division, June 2005.

¹⁷ Hazard Mitigation Survey Team Report for the Nisqually Earthquake, February 28, 2001, DR-1361-WA, Federal Emergency Management Agency and Washington Military Department, Emergency Management Division, p. 13.

¹⁸ Scenario for a Magnitude 6.7 Earthquake on the Seattle Fault, Earthquake Engineering Research Institute and the Washington Military Department, Emergency Management Division, June 2005, p. 1.

¹⁹ Cascadia Subduction Zone Earthquakes: A magnitude 9.0 earthquake scenario, Cascadia Region Earthquake Workgroup, 2005, p.2.

²⁰ Naghii MR. Public health impact and medical consequences of earthquakes. Rev Panam Salud Publica.

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²¹ Rubble Dust: A Health Risk For Haiti's Earthquake Survivors?, Richard Knox NPR online,

http://www.npr.org/blogs/health/2010/01/rubble_dust_a_health_risk_for.html?ft=1&f=103537970 Worry amongst

health experts of respiratory problems for Haitians. He references Dr. Landrigan who has been involved in medical and epidemiological studies on the after affects of the World Trade Center collapse.

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²³ Johnson Sherrard, Linda, Heroes on Call, Occupational Health and Safety, March 2007,

<http://www.ohsonline.com/articles/45373>

²⁴ For a more in depth look at the long term effects on first responders see Mitchell, Jeff and Bray, Grady, Emergency Services Stress: Guidelines for Preserving the Health and Careers of Emergency Services Personnel, Brady, Prentice Hall Career & Technology, Englewood Cliffs, New Jersey 1990, and Jackson, Brian A. et al., Protecting Emergency Responders: Lessons Learned from Terrorist Attacks, Rand Science and Technology Institute, Proceedings from the Conference December 9-11, in New York City.

²⁵ Field Manual: Postearthquake safety evaluation of Buildings, Second edition, Project Manager: Christopher Rojhan, Applied technology Council, Redwood City, California, 2005, p. 45.

²⁶ Post Earthquake Safety Evaluation of Buildings, ATC -20 Instruction Slide Show, Project Manager: Christopher Rojhan, Applied technology Council, Redwood City, California, 2005.

²⁷ **Geotechnical Earthquake Engineering Server (GEES)** of the University of Southern California sponsored by the Siting and Geotechnical Systems component of the National Science Foundation's Earthquake Hazard Mitigation program, <http://gees.usc.edu/GEER/Nisqually/liquefaction/lateralspread/index.html>