# Section III

# Risk Analysis

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# Risk Assessment

## *Introduction*

This chapter will look at the potential hazards that could affect the Tulalip Reservation, and then determine the vulnerabilities of people, property and the environment.

An inventory of Tribally-owned property, critical facilities and infrastructure on the Tulalip Reservation was used to determine loss estimations. In addition, one section will review the hazards that could affect Tulalip's Usual and Accustomed fishing areas (U&A), which are located elsewhere in the region and are not under the land management or jurisdiction of the Tribe.

The format of the chapter will be as follows:

- Introduction and overview, including methodology and summary of findings
- Detailed profiles of natural hazards affecting Tulalip, including loss estimations
- Additional hazards: Pandemic, Heat Wave, Drought and Hazardous Materials
- Usual and Accustom fishing area, including vulnerabilities
- Critical Facilities and Infrastructure assessments
- Hazard Risk Rating

## *Hazards Profiled*

The first step in preparing a risk assessment for the Tulalip Reservation is to identify which natural hazards affect the Reservation. The 2006 Hazard Mitigation Plan identified the hazards that have previously affected the reservation:

- Earthquakes
- Floods
- Landslides/Mass Movements
- Severe Weather
- Tsunamis/Seiches
- Wildfires

Due to the 2009 H1N1 influenza pandemic, the 2010 Mitigation Planning Team chose to include Pandemic as a natural hazard to facilitate distribution of medication and supplies, and to ensure continuity of operations during a mass casualty event. Recent events such as the record high temperatures during the summer of 2009 and the concern stated in the Tulalip Comprehensive Plan of maintaining sufficient water availability led to the Mitigation Update Committee adding heat wave and drought as hazards to be considered. The Committee agreed that integrating the predicted effects of climate change into the updated plan is important; increased frequency and severity of Heat Wave and Drought are one of the predicted consequences of climate change in this area.

Avalanches and volcanic eruptions were excluded from the hazards studied. The Tulalip Reservation is located along the coast, and does not have the steep rugged mountains or snow cover needed to experience avalanches. The Tulalip Reservation is west of a volcano, Glacier Peak, but is not considered a risk to the Reservation due to river drainage courses and prevailing winds. Most ash and smoke (tephra) would blow east, particularly with the strong winds of the Convergence Zone. Lava and mudflows (lahars) would not flow through any watersheds that drain the Reservation. These hazards could affect the Usual and Accustomed Fishing Areas. A volcanic eruption would have severe effects on the natural environment and would disrupt fisheries that the Tulalip Tribes depend on.

## Summary of Vulnerability and Losses

Overall the Tulalip Reservation and the Puget Sound estuary, of which the Tulalip Tribes' Usual and Accustomed fishing area is part, are extremely vulnerable to natural hazards. The Tulalip Reservation lies within one of the most seismically and volcanically active regions on Earth. In particular 2-3 crustal faults, of which little is known, run just north and south of the Reservation. Every year brutal winter storms batter the coast, flooding low lying areas and damaging property. The most recent event was the record snowstorm of 2009, during which many roads in the Puget Sound area were impassable. Furthermore the Reservation is walled by imposing unstable cliffs carved by recent glaciations that reach up to 300 feet high and can collapse at any time and without warning onto properties below.

### Presidential Declared Disasters

Presidential Declared Disasters are typically events that cause more damage than state, tribal and local governments/resources can handle without the assistance of the federal government. Generally there is not a specific dollar loss threshold that must be met. A Presidential Major Disaster Declaration puts into motion long-term federal recovery programs, some of which are matched by state programs, and designed to help disaster victims, businesses, and public entities.

Historically, Snohomish County has had 23 Presidential Declared Disasters with the frequency increasing over the past ten years. The most recent declaration occurred March 2nd, 2009 for the major snowstorms that shut down the region for several days. Five disasters have been declared for major winter storms in the last four years. The winter of 2009-2010 was mild due to El Nino, but it is likely that winter storms will continue to occur regularly in the Tulalip area.

Presidential declarations are listed in Table 3. It is not known at this time how much damage the Tulalip Reservation received from these disasters, nor how much financial assistance was given to Tribal members and residents of the Reservation. It has been noted by Tribal staff during meetings that the Tulalip Tribes had difficulty getting assistance after the Nisqually earthquake in 2001. For future events, it is essential that the Tulalip Tribes apply directly to FEMA for disaster assistance rather than through Snohomish County. Not only will a better assessment be made of damages, but more financial assistance is possible.

| Disaster # | Type of Event | Date |
|---|---|---|
| 137 | Flood, Wind | October 1962 |
| 185 | Flood | December 1964 |
| 196 | Earthquake | May 1965 |
| 492 | Flood | December 1975 |
| 545 | Flood, Landslide | December 1977 |
| 612 | Flood | December 1979 |
| 623 | Volcano | May 1980 |
| 784 | Flood | November 1986 |
| 883 | Flood | November 1990 |
| 896 | Flood | December 1990 |
| 981 | Wind | January 1993 |
| 1079 | Flood | November-December 1995 |
| 1100 | Flood | January-February 1996 |
| 1159 | Ice, Wind, Snow, Landslide, Flood | December 1996-February 1997 |
| 1172 | Flood, Landslide | March 1997 |
| 1361 | Earthquake | February 2001 |
| 1499 | Severe Storm, Flooding | November 2003 |
| 1641 | Severe Storms, Flooding, Tidal Surge, Landslides, and Mudslides | May 17th, 2006 (for storm Jan. 27th- Feb 4th, 2006) |
| 1671 | Severe Storms, Flooding, Landslides, and Mudslides | Dec 12, 2006 (for storms Nov 2-11th, 2006) |
| 1682 | Severe Winter Storm, Landslides, and Mudslides | Feb 14, 2007 (for storm Dec 14-15th, 2006) |
| 1734 | Severe Storms, Flooding, Landslides, and Mudslides | Dec 8th, 2007 |
| 1817 | Severe Winter Storm, Landslides, Mudslides, and Flooding | Jan 30th, 2009 |
| 1825 | Severe Winter Storm and Record and Near Record Snow | Mar 2nd, 2009 (for storms Dec 12th-Jan 5th, 2009) |

*Table 3: Presidential Declared Disasters*

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# Earthquakes

## *Hazard Profile*

Earthquakes are caused by the fracture and sliding of rock within the Earth's crust. The Earth's crust is divided into eight major pieces (or plates) and many minor plates. These plates are constantly moving, very slowly, over the surface of the globe. As these plates move, stresses are built up in areas where the plates come into contact with each other. Within seconds, an earthquake releases stress that has slowly accumulated within the rock, in some instances over hundreds of years. Sometimes the release occurs near the surface, and sometimes it comes from deep within the crust.

The Puget Sound region has hundreds of earthquakes occurring each year, most of them so small that only sensitive instruments can detect them. There have been at least 20 damaging earthquakes in Western Washington over the past 125 years. Large quakes in 1946, 1949, 1965 and 2001 killed 16 people and caused more than $3.59 billion (2004 dollars) in property damage.

Scientists generally agree that three source zones exist for Puget Sound quakes: a shallow (crustal) zone; the Cascadia Subduction zone; and a deep or intraplate ("Benioff") zone. More than 90% of all Pacific Northwest earthquakes occur along the crustal plate boundary between the Juan de Fuca plate and the North American plate.

Part of assessing how much of a risk earthquakes are to an area is estimating what the ground motion would be during an earthquake of a certain magnitude. A scenario is usually the most useful way to estimate possible damages. The factors that must be identified in order to estimate ground motions are earthquake magnitude, type of faulting, distance of the site from the epicenter, and local site conditions (hard rock, soft soil, etc).

For instance, the scenario used for this plan was a 7.4 magnitude earthquake on the crustal South Whidbey Island fault. Based on the distance from that epicenter, approximately half of the reservation is at risk of experiencing moderate to severe damage, while the remainder is at risk of slight to moderate damage. In some areas the risk is higher due to soft soils that are at higher risk of liquefaction during certain types of earthquakes.

A major element involved in earthquake hazard assessment is predicting the type and severity of ground motion that could happen during a quake. The most commonly mapped ground motion factors are the horizontal and vertical peak ground accelerations (PGA) for a given site classification (soil or rock type). Maps of PGA values now form the basis of seismic zone maps that are included in building codes, including the U.S. Uniform Building Code (UBC). Building seismic codes specify the lateral forces that a building should be able to withstand during an earthquake. PGA values are directly related to these lateral forces that could damage "short period structures" (i.e. single-family dwellings, the most common structures in the county). Maps may also need to be developed to determine the lateral forces that damage larger structures (apartment buildings, factories, high-rises, bridges).

The impact of any earthquake event is largely a combination of ground shaking, liquefaction and distance from the source of the quake. Liquefaction usually occurs only in soft, loose soils. A program called the National Earthquake Hazard Reduction Program (NEHRP) creates maps based on soil characteristics to identify areas potentially subject to liquefaction. **Table 4** provides a description of the NEHRP soil classification.

| NEHRP Soil Classification System | |
|---|---|
| **NEHRP Soil Type** | **Description** |
| A | Hard Rock |
| B | Firm to Hard Rock |
| C | Dense soil, soft rock |
| D | Stiff Soil |
| E | Soft clays |
| F | Special study soils (liquefiable soils, sensitive clays, organic soils, soft clays > 36 m thick) |

*Table 4: NEHRP Soil Classification System*

## Richter Scale

The Richter magnitude scale is probably the most familiar earthquake rating system for the average person. It compares the size of earthquakes, calculated using waves recorded by seismographs. On the Richter Scale, each whole number (e.g. 5.5 to 6.5) increase in magnitude represents a tenfold increase in measured amplitude; as an estimate of energy, each whole number step in the magnitude scale corresponds to the release of about 31 times more energy.

Great earthquakes, such as the 1964 Good Friday earthquake in Alaska, have magnitudes of 8.0 or higher. On the average, one earthquake of such size occurs somewhere in the world each year. Although the Richter Scale has no upper limit, the largest known shocks have had magnitudes in the 8.8 to 8.9 range.

The Richter Scale is not used to express damage. An earthquake in a densely populated area which results in many deaths and considerable damage may have the same magnitude as a shock in a remote area that does nothing more than frighten the wildlife. **Table 5** shows a description of Richter scale magnitudes.

| Richter Scale | | | |
|---|---|---|---|
| **Descriptor** | **Richter magnitudes** | **Earthquake Effects** | **Frequency of Occurrence (worldwide)** |
| Micro | Less than 2.0 | Micro-earthquakes, not felt. | About 8,000 per day |
| Very minor | 2.0-2.9 | Generally not felt, but recorded. | About 1,000 per day |
| Minor | 3.0-3.9 | Often felt, but rarely causes damage. | 49,000 per year (est.) |
| Light | 4.0-4.9 | Noticeable shaking of indoor items, rattling noises. Significant damage unlikely. | 6,200 per year (est.) |
| Moderate | 5.0-5.9 | Can cause major damage to poorly constructed buildings over small regions. At most slight damage to well-designed buildings. | 800 per year |
| Strong | 6.0-6.9 | Can be destructive in areas up to about 100 miles across in populated areas. | 120 per year |
| Major | 7.0-7.9 | Can cause serious damage over larger areas. | 18 per year |
| Great | 8.0-8.9 | Can cause serious damage in areas several hundred miles across. | 1 per year |
| Rare great | 9.0 or greater | Devastating in areas several thousand miles across. | |

*Table 5: Richter Scale*

## Modified Mercalli Scale

The degree of ground shaking, and therefore damage, caused by an earthquake is assigned a Roman Numeral between I and XII on the Modified Mercalli (MM) Scale and is referred to as intensity. This helps to assess and understand the physical affects of the earthquake. **Table 6** provides a comparison of Peak Ground Acceleration to the MM Intensity scale. Unreinforced masonry (URM) buildings are particularly vulnerable during earthquakes due to how they are constructed. Usually older, brick buildings, historically these have caused the most damage, injury and death due to collapse during major earthquakes. The 2005 Sichuan Earthquake, for instance, occurred in an area where nearly all housing structures were unreinforced masonry buildings, causing widespread devastation.

| Mercalli Scale and Peak Ground Acceleration Comparison | | |
|---|---|---|
| **MM** | **Potential Damage** | **PGA** |
| I | None | < .017 |
| II – III | None | .017 |
| IV | None | .014 - .039 |
| V | Very Light | .039 - .092 |
| VI | None to Slight | .02-05 |
| | Unreinforced Masonry:<br>Stair-step cracks<br>Damage to chimneys<br>Minimum threshold of any damage | .04-.08<br>.06 - .07<br>.06 - .13<br>.092 - .18 |
| VII | Slight – Moderate | .05.-10 |
| | Unreinforced Masonry:<br>Significant cracking of parapets<br>masonry may fall<br>Minimum threshold of structural damage | .08-.16<br>.10 - .15<br>.1<br>.18-.34 |
| VIII | Moderate – Extensive | .10 - .20 |
| | Unreinforced Masonry:<br>Fall of parapets and gable ends<br>Extensive cracking | .16 - .32<br>.25 - .30<br>.13 - .26<br>.2<br>.35 - .65 |
| IX | Extensive – Complete | .20 - .50 |
| | Unreinforced Masonry:<br>Structural collapse of some buildings<br>Walls out of plane<br>Damage to seismically designed structures | .32 - .55<br>.50 - .55<br>.26 - .44<br>.3<br>.65 – 1.24 |
| X | Complete | .50 – 1.00 |
| | Unreinforced Masonry:<br>Structural collapse of most buildings<br>Notable damage to seismically designed structure<br>Ground Failures | .55 - .80<br>>.6<br>.44 - .64<br>> 1.24 |

*Table 6: Mercalli Scale and PGA Comparison*

## Past Events

There have been several earthquakes in the past that have affected the Puget Sound Region and more specifically the Tulalip Reservation. The actual effect of these earthquakes on the Tulalip Reservation has been less severe that in other areas within the region, but nonetheless significant damage has occurred to the older and dilapidated structures on the reservation. **Table 7** is a summary of large earthquakes that have occurred in the Puget Sound Region.

| Large Earthquakes in the Puget Sound Region | | | |
|---|---|---|---|
| Date | Location | Magnitude | Type |
| **1872** | **North Cascades** | **7.4** | **Crustal Zone** |
| 75 miles NE of Everett, near Mount Baker and just east of the Cascade crest (largest recorded earthquake in Washington). No record of any fatalities in Snohomish County. | | | |
| 1882 | Olympic Area | 6.0 | Benioff Zone |
| 1909 | Puget Sound | 6.0 | Benioff Zone |
| 1915 | North Cascades | 5.6 | -- |
| 1918 | Vancouver Island | 7.0 | -- |
| 1920 | Puget Sound | 5.5 | -- |
| 1932 | Central Cascades | 5.2 | Crustal Zone |
| 1939 | Puget Sound | 5.8 | Benioff Zone |
| 1945 | North Bend | 5.5 | Crustal Zone |
| 1946 | Puget Sound | 6.3 | Benioff Zone |
| 1946 | Vancouver Island | 7.3 | Benioff Zone |
| **1949** | **Olympia** | **7.1** | **Benioff Zone** |
| Nisqually Delta Area: Effects included fallen chimneys and building cornices; cracked plaster; broken water and gas mains; damaged docks, bridges, and water storage tanks; cracked ground and pavement; and landslides, mudflows and debris slides. | | | |
| 1965 | Puget Sound | 6.5 | Benioff Zone |
| 1981 | Mt. St. Helens | 5.5 | Crustal Zone |
| 1990 | NW Cascades | 5.0 | Crustal Zone |
| 1995 | Robinson Point | 5.0 | Crustal Zone |
| **1996** | **Duvall** | **5.6** | **--** |
| Duvall: Near the epicenter, merchandise fell off of shelves and at least one chimney cracked. In Snohomish County, 16,000 residents were without power for several hours. | | | |
| **2001** | **Nisqually\Puget Sound** | **6.8** | **Benioff Zone** |
| Nisqually Delta Area North of Olympia: Damages between $2 million and $3 million in Snohomish County, 13 minor injuries. A few unreinforced masonry structures suffered significant damage, but there were no building collapses. The greatest shaking was in cities or towns built along the rivers. Tulalip also experienced significant damage to its structures. It is estimated that at least 80% of Tribal housing had some damage from the quake. | | | |

*Table 7: Large Earthquakes in the Puget Sound Region*

## Location

The Tulalip Reservation is located in one of the most earthquake prone regions of the United States. This section will detail the different types of earthquakes that can affect the Reservation.

In Western Washington, the primary plates of interest are the Juan De Fuca and North American plates. The Juan De Fuca plate moves northeastward with respect to the North American plate at a rate of about 4cm/yr. The boundary where these two plates converge, the

Cascadia Subduction Zone, lies approximately 50 miles offshore of the coastline and extends from the middle of Vancouver Island in British Columbia to northern California. As it collides with the North American plate, the Juan De Fuca plate subducts beneath the continent, sinking into the earth's mantle.

The three source zones that exist for Puget Sound quakes are a shallow or crustal zone; the Cascadia Subduction zone; and a deep, intraplate, or Benioff zone, as shown in **Figure 8**.

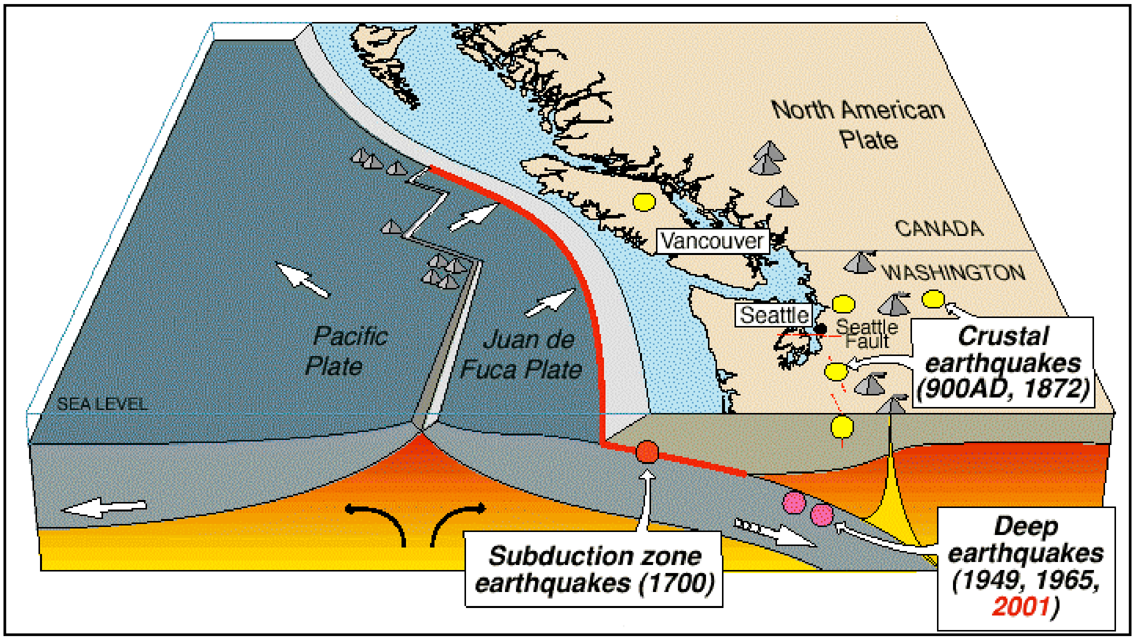



*Figure 8: Earthquake Types in Western Washington*

## Cascadia Subduction Zone

Subduction Zone earthquakes are the world's greatest earthquakes and are observed at subduction zone boundaries. A Cascadia subduction earthquake would be centered off the coast of Washington or Oregon where the plates converge. There would typically be a minute or more of strong ground shaking. These magnitude 8 to 9.5 Richter scale thrust-type subduction earthquakes occur from time to time as two converging plates slide past one another. There are no reports of such earthquakes in the Cascadia Subduction Zone off the Oregon/Washington coast since the first written records of permanent occupation by Europeans in 1833. However, paleoseismic evidence suggests that there may have been as many as five of these devastating energy releases in the past 2000 years, with a very irregular recurrence interval of 150 to 1100 years. Written tsunami records from Japan, correlated with studies of partially submerged forests in coastal Washington and Oregon, give a probable date for the most recent of these huge quakes as January 26, 1700.

Since the installation in 1969 of a multi-station seismograph network in Washington, there has been no evidence of even small subduction-type earthquakes in the Cascadia region, indicating the plates are locked. However, parts of subduction zones in Japan and Chile also appear to have had very low levels of seismicity prior to experiencing great earthquakes. Recent shallow geodetic strain measurements near Seattle indicate that significant compressional strain is accumulating parallel to the direction of convergence between the Juan de Fuca and North America plates, as would be expected prior to a great thrust earthquake off the coast of Oregon, Washington and British Columbia. Usually, these types of earthquakes are immediately followed by damaging tsunamis and numerous large aftershocks.

### Benioff (Deep) Zone

Western Washington is most likely to experience intraplate or "deep" earthquakes of magnitude 6 to 7.4 on the Richter scale. This occurs within the subducting Juan de Fuca plate at depths of 50 - 70 km (30 - 45 miles). As the Juan de Fuca plate subducts beneath North America, it becomes denser than the surrounding mantle rocks and breaks apart under its own weight, causing Benioff zone earthquakes. The Juan de Fuca plate begins to bend even more steeply downward, forming a 'knee'. It is at this knee where the largest Benioff zone earthquakes occur.

The largest of these events recorded in modern times were the 7.1 magnitude Olympia earthquake in 1949 and the 6.8 magnitude Nisqually earthquake in 2001. Strong shaking during the Olympia earthquake lasted about 20 seconds. For the Nisqually quake, duration of shaking in Snohomish County varied from about 30 seconds to more than 2 minutes. Scientists estimate this type of quake will occur once every 30 - 40 years for magnitude 6.5, and once every 50 - 70 years for magnitude 7.0. Because of their depth, intraplate earthquakes are least likely to produce significant aftershocks.

### Crustal Zone

The third source zone of earthquakes is the crust of the North American plate, known as shallow earthquakes. Of the three source zones, this is the least understood. The Puget Lowland area is currently shortening north-south at a rate of about 0.5 cm (one-fifth of an inch) per year. Shallow earthquakes of magnitude up to 7.0 or more on the Richter scale can happen anywhere in the Puget Sound region. Such earthquakes have the potential to cause greater loss of life and property on the Tulalip Reservation than any other kind of disaster. Fortunately, great crustal quakes do not seem to happen very often: perhaps no more than once every 1000 years.

In addition to the 1872 Mount Baker earthquake, seismologists have found evidence that a devastating crustal quake occurred on a fault near Seattle approximately 1100 years ago. Several major fault zones cross Whidbey Island and run east to southeast into Snohomish County. Seismologists have recently identified a near-surface fault zone in the northeast corner of Snohomish County near the Town of Darrington. This fault, the Darrington Seismic Zone Devil's Mountain Fault - North Whidbey Fault complex, is estimated to be capable of generating at least a 6-7 magnitude crustal earthquake on the Richter scale. The Duvall Fault near Lake Margaret on the King - Snohomish County border has produced two (magnitude 5.2 and 5.6) earthquakes in the past 70 years (1932 and 1996).

Crustal earthquakes are the most likely to be followed by significant aftershocks. Following a great crustal earthquake of magnitude 7.0 or more, one of the greatest dangers to human life is that buildings or other structures damaged in the initial shock but still in use and believed safe could collapse in a strong aftershock.

Geologists and geophysicists are studying the South Whidbey Island fault and the Olympia fault for evidence of recent earthquakes. A potential Everett fault has been identified and is currently being researched. Recently, there has been a study of earthquake activity in the Snohomish River Delta region. In particular, the scientists have found two crustal events from around 900-950 AD and 1450-1620 AD.

The Tulalip Reservation is located in a basin of softer soils, known as the Everett Basin, which can intensify the effect of an earthquake. The Reservation is also located between the two recently identified crustal faults mentioned above known as the Devil's Mountain Fault and the South Whidbey Fault. **Figure 9** shows these faults and the location of the Reservation in yellow.

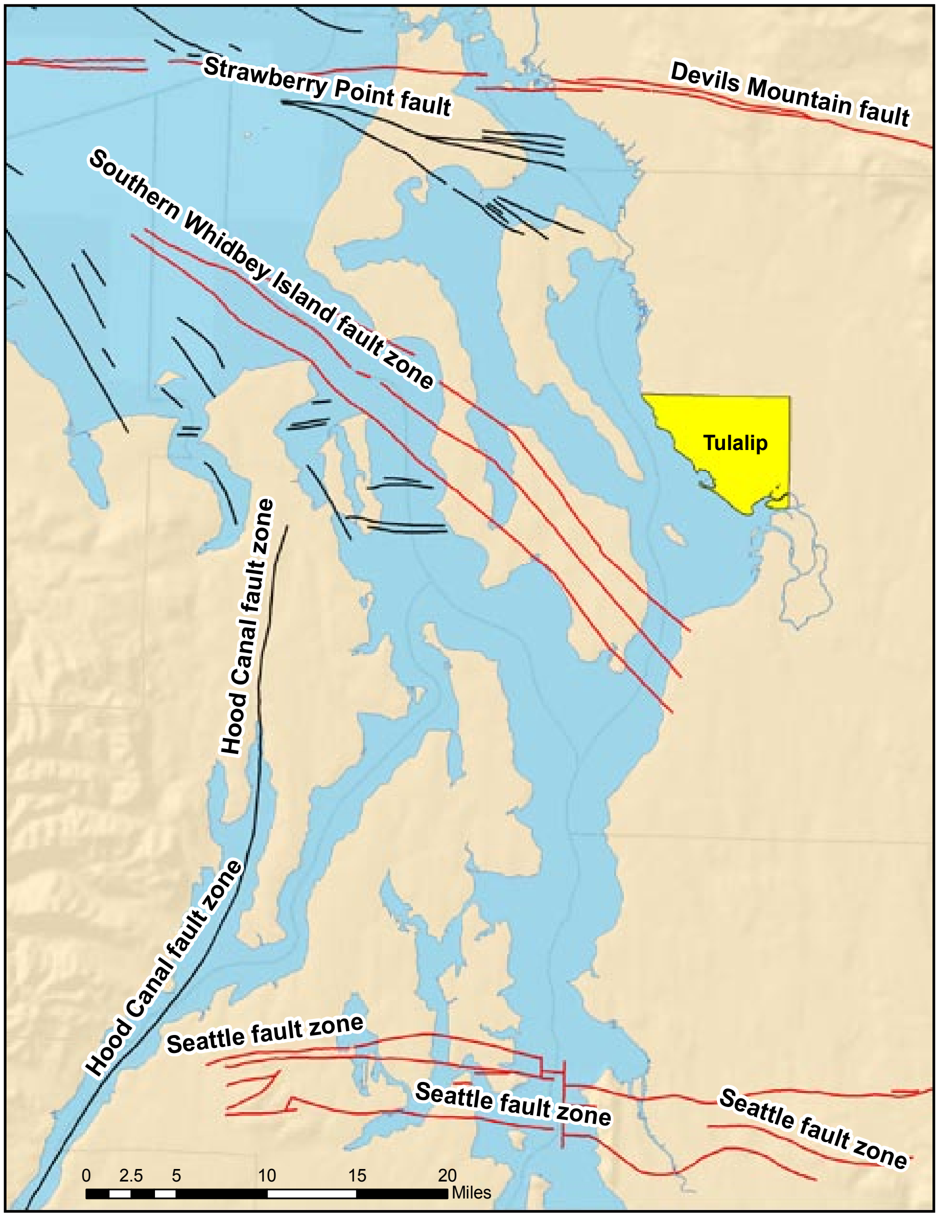



*Figure 9: Faults near Tulalip Reservation*

## National Earthquake Hazard Reduction Program (NEHRP)

The soil makeup of the Reservation further determines the areas that will be more affected by an earthquake event. The NEHRP classification system identifies which types of soil are at greater risk during an earthquake. The areas that will be most affected by ground shaking are located in NEHRP soils D, E and F. In general these areas will also be most susceptible to liquefaction, a secondary effect of an earthquake where soils can temporarily act like quicksand, leading to sudden drops in land level and damage to roads, buildings and utility lines. The NEHRP Liquefaction Risk for the Tulalip Reservation are shown **Map 8**.

## Frequency

The USGS has created a probabilistic hazard map based on peak ground acceleration that takes into account information on several fault zones. The Puget Sound area, including the Tulalip Reservation, is in a higher risk area from a Subduction Zone event.

Dr. Art Frankel of the USGS estimated that a Cascadia Subduction zone earthquake has a 10% to 15% probability of occurrence in 50 years. A crustal zone earthquake in general has a recurrence interval of about 500 to 600 years. A Benioff zone earthquake has an 85% probability of occurrence in 50 years, the most likely to occur of all types of earthquake events. The South Whidbey and Seattle faults have a 2% probability of an earthquake occurring in 50 years. The Devil's Mountain Fault - North Whidbey Fault complex does not yet have enough information to determine the probability of occurrence of this event. The probability of an earthquake greater than Magnitude 6.0 occuring in the next 50 years is graphed in **Figure 10.**

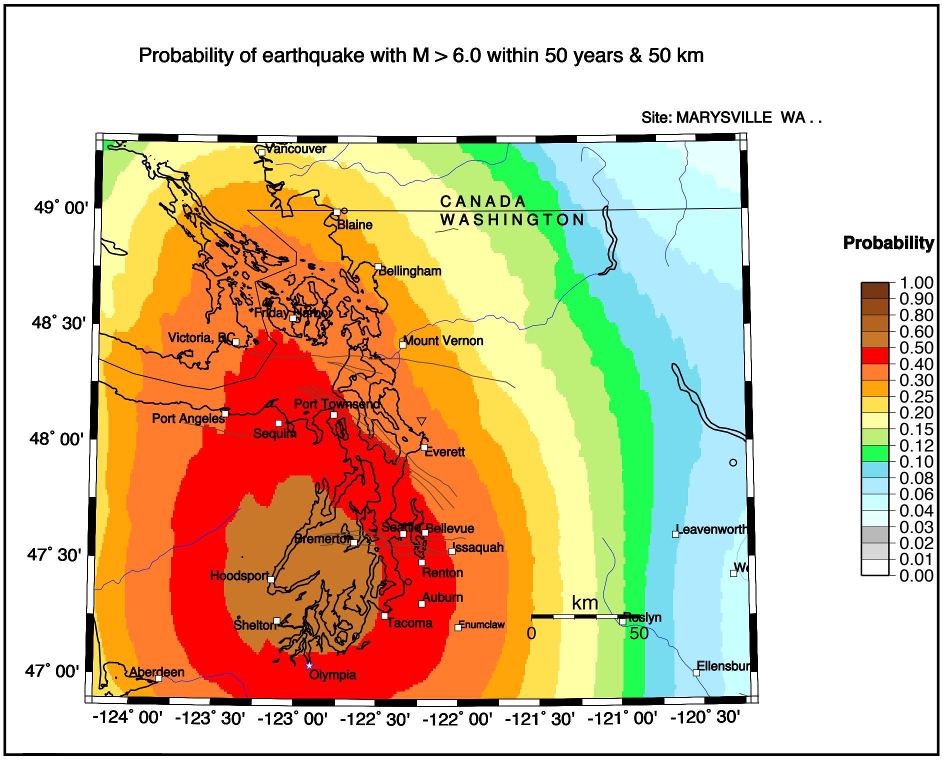



*Figure 10: Probabilistic Hazard Map*

## Severity

A subduction zone earthquake could produce an earthquake with a magnitude 8.5 Richter scale on the Reservation. Benioff zone earthquakes as large as magnitude 7.1 are expected everywhere west of the eastern shores of Puget Sound. A crustal zone earthquake could produce a 7.1 magnitude earthquake affecting the Reservation. **Table 8** provides a description of the expected severity of the earthquakes.

| Type of Earthquake | Expected Magnitude |
|---|---|
| Cascadia Subduction Zone | 9.0 for approximately 4 minutes with aftershocks |
| Benioff | 7.1 with no aftershocks |
| Crustal *(North Whidbey Devil's Peak Complex; South Whidbey; Everett Fault)* | 7.1 with some aftershocks |

*Table 8: Severity of Tulalip Reservation Earthquakes*

## Warning Time

There is no current way to predict what day or month an earthquake will occur at any given location.

## Secondary Hazards

There are several secondary effects of earthquakes. Earthquakes can cause large and sometimes disastrous landslides and mudslides, including debris flows from volcanoes (lahars) not directly associated with eruptions. Soil liquefaction occurs when water-saturated sands, silts or gravelly soils are shaken so violently that the individual grains lose contact with one another and "float" freely in the water, turning the ground into a pudding-like liquid. Building and road foundations lose load-bearing strength and may actually sink, quicksand-like, into what was previously solid ground. Lastly, unless properly secured, hazardous materials releases can cause significant damage to the surrounding environment and people.

Tsunamis and seiches are also a major secondary hazard caused by earthquakes. These can be caused directly by the earthquake, or by an earthquake-induced landslide into Puget Sound or other bodies of water.

## *Exposure Inventory*

Earthquakes were profiled for The Tulalip Reservation by using two methodologies: using GIS data to determine the location of earthquakes, particularly the NEHRP soils that can exaggerate the effects of an earthquake; and by using Hazus-MH, which was used to model the potential severity of different types of earthquakes, and how the Reservations' assets could be affected.

This section will detail the Tulalip Reservation's inventory of people, property, and infrastructure exposed to earthquakes. 2009 Snohomish County Assessor's data and the Tulalip Tribes' GIS database of buildings and critical facilities were used to identify property listed in this inventory.

### Loss Estimation

FEMA has developed a detailed methodology using HAZUS-MH software to estimate damages from earthquakes based on the strength and location of an earthquake and also the characteristics of Tulalip structures, such as year built, foundation and building materials, such as wood-frame, tilt-up or steel frame. Unfortunately, at this time it is not possible to conduct a detailed inventory of all structures on the Tulalip Reservation to come up with an accurate loss estimate.

All of its assets are exposed to the different kinds of earthquakes that can occur in the Puget Sound area. The inventory and damage functions to all population, critical infrastructure and parcels is detailed as Earthquake: PGA (Peak Ground Acceleration).

The parcels, critical infrastructure and population located on NEHRP rated medium or high liquefaction risk areas are detailed as Earthquake: Liquefaction.

For this estimate, general values were used. The values used in this loss estimation are a hypothetical estimate of all potential damage.

## Vulnerability

Older structures, such as housing built before seismic codes were introduced in the 1980s, are vulnerable to earthquakes. Homes located on, above or below steep slopes are vulnerable due to the secondary hazards associated with earthquakes, such as landslides.

Most vulnerable are the older critical and historic Tribal structures that were not built to current earthquake standards and have already experienced earthquakes. This includes many structures located in Tulalip Bay, such as St. Anne's Church and the Tribal Center. Other vulnerabilities include tribal housing, most of which were built below earthquake codes and were already damaged by the Nisqually quake.

*Assumptions*

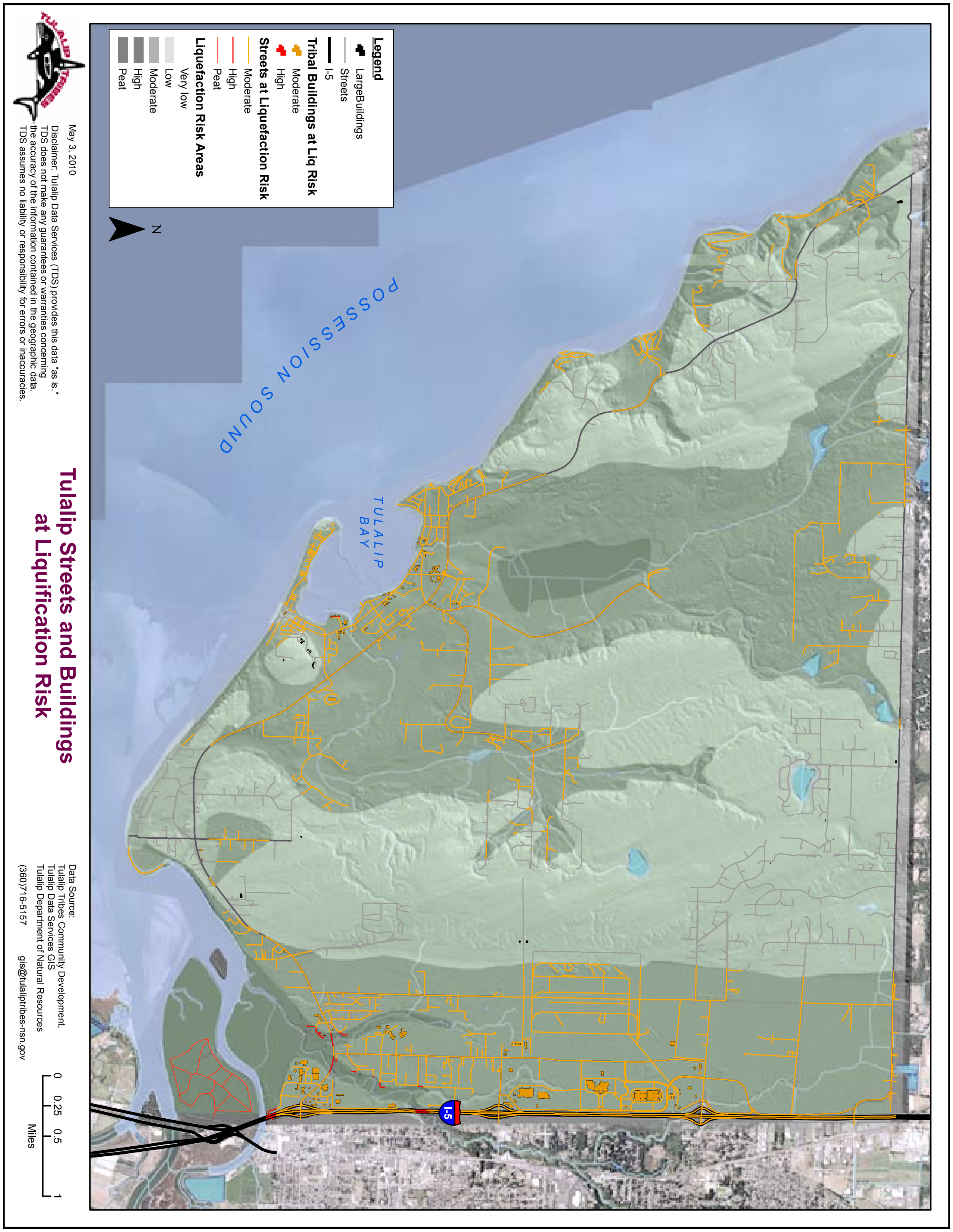
- PGA value used for this estimate is 0.4%.
- The estimated damage to wood frame structures (which most Tulalip buildings are, built pre-code, is 16.7% of improvement value
- FEMA suggests that damage to content value be estimated as ½ of the damage to improvements, or 8.35%

| Earthquake: PGA | Improvements | | | Land / Buildings | | Contents | | | Daily Sales | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Exposed | | Damage | Exposed | | Exposed | | Damage | | |
| Parcels | $490.9 M | 100% | $24.5 M | $736.0 M | 100% | $245.4 M | 100% | $24.5 M | | |
| Critical Buildings | $335.5 M | 100% | $16.8 M | 157 | 100% | $354.1 M | 100% | $35.4 M | $882 K | 100% |

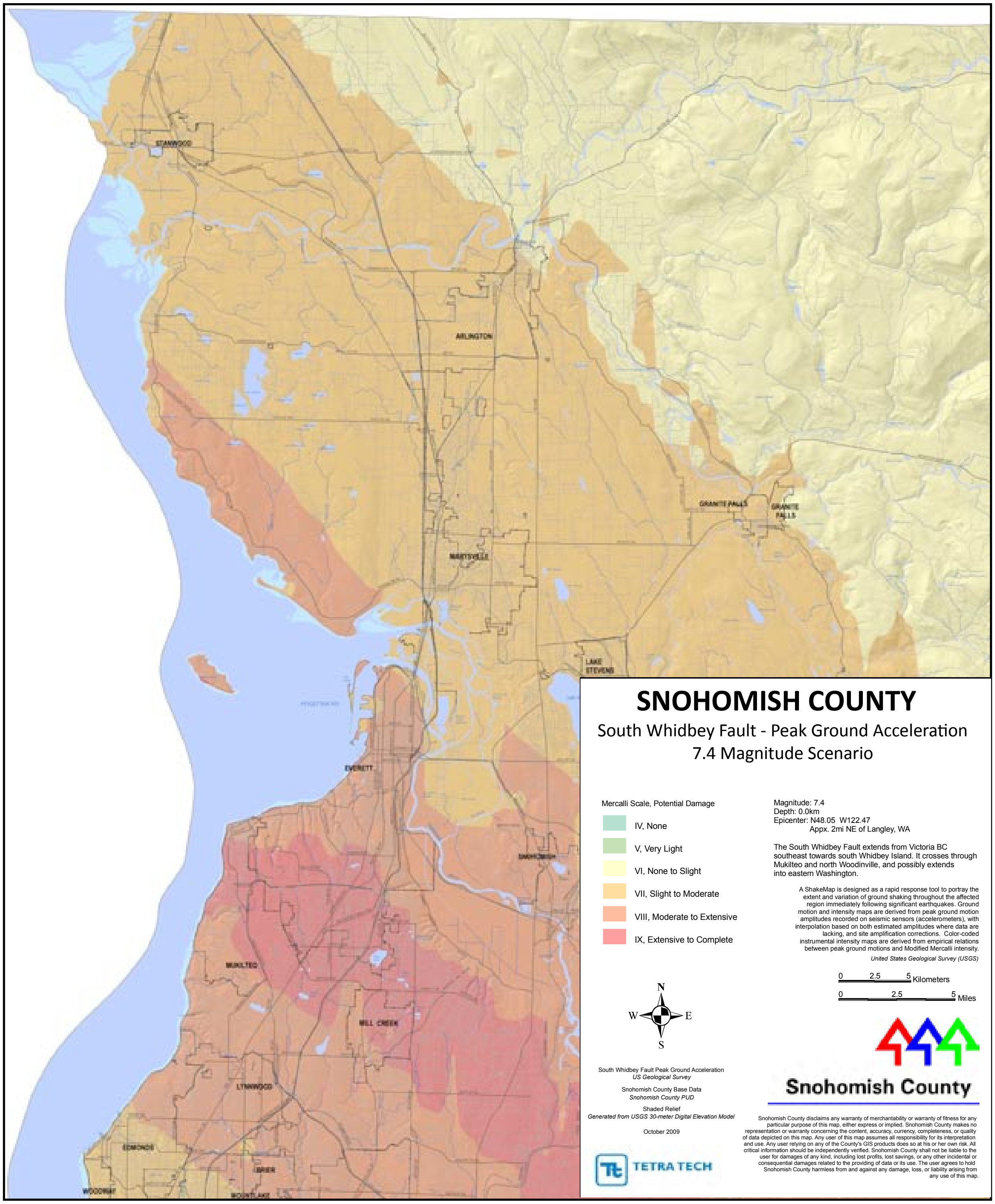
| Earthquake: PGA | At Risk | % of Total |
|---|---|---|
| Population | 9246 | 100% |
| Vulnerable Population | 1069 | 100% |

| Earthquake: Liquefaction | Improvements | | | Land / Buildings | | Contents | | | Daily Sales | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Exposed | | Damage | Exposed | | Exposed | | Damage | | |
| Parcels | $212.4 M | 43% | $35.5 M | $402.0 M | 55% | $106.2 M | 43% | $17.7 M | | |
| Critical Buildings | $214.4 M | 64% | $35.8 M | 104 | 66% | $223.1 M | 63% | $17.9 M | $328 K | 37% |

| Earthquake: Liquefaction | At Risk | % of Total |
|---|---|---|
| Population | 5710 | 62% |
| Vulnerable Population | 735 | 69% |




*Map 8: NEHRP Liquefaction Risk Zones*




*Map 9: South Whidbey Island Fault 7.4 Scenario Shakemap*

*(Courtesy of Snohomish County Emergency Management and Tetra Tech)*

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# Severe Storms

## *Hazard Profile*

Tulalip's location on the Puget Sound, between the Cascade and Olympic Mountain Ranges, gives it a predominantly marine-type climate with heavy rainfall during the winter months and mild summers. While measurable rainfall occurs between 150-190 days each year, there are typically only about a dozen thunderstorms per year. The rainy season is characterized by light to moderate continuous rainfall, rather than brief heavy downpours. Wind velocities reach 40 to 50 mph every winter, and on rare occasions gust between 75 to 90 mph. Extreme wind velocities can be expected to reach 50 mph at least once in two years; 60 to 70 mph once in 50 years; and 80 mph once in 100 years.

During the coldest months there can be freezing drizzle and snow accumulation in low elevations every few years, although in the mountains several inches to feet of snow is standard, in some cases nearly year-round. Chinook winds from the Pacific can bring a rapid increase in temperatures over the Cascades, causing rapid snow melt and flooding.

Severe weather in the area regularly consists of heavy rains and windstorms, with occasional snow and ice storms. Tornados are possible but rare. Tulalip is located at the northern edge of the Puget Sound Convergence Zone, where the jet stream re-converges after being split around the Olympic Mountains. In this area, the air currents rise and cause precipitation and high winds, creating more extreme weather than that typically found outside of the Convergence Zone, which stretches south to Seattle.

### Past Events

Snohomish County has had a severe weather event nearly every year for the past three decades. While information about damages on the Tulalip Reservation in particular are not available for the majority of events, potential types of damage and the frequency of occurrence can be extrapolated from information about the general area. For past events of flooding refer to the later section on Flooding. **Table 9** outlines the major severe weather events that have affected Tulalip and Snohomish County in the past 60 years.

| Date | Event Type | Notes |
|---|---|---|
| January 13, 1950 | Snowstorm | Nearly 2’ of snow in Seattle |
| November 1961 | Snowstorm | |
| October 12, 1962 | Windstorm | Hurricane force winds, widespread destruction |
| January 1969 | Snowstorm | |
| 1970 | Tornado | Marysville |
| 1971 | Tornado | Lake Roesinger |
| January 1980 | Snowstorm | |
| November 1981 | Windstorm | Record high winds |
| December 1990 | Snowstorm | Federal Disaster #896 |
| January 1991 | Snowstorm | |
| January 20, 1993 | Windstorm | Federal Disaster #981 |
| December 1995 | Windstorm | California Express Windstorm |
| December 1996-January 1997 | Snowstorm | Federal Disaster #1159 |
| January 2, 1997 | Tornado | Granite Falls |
| May 31, 1997 | Tornado | Lake Stevens |
| June 8, 1997 | Tornado | Darrington |
| July 6, 1997 | Tornado | Snohomish |
| December 8, 1997 | Tornado | Snohomish |
| September 1, 1998 | Tornado | Monroe |
| January - March 1999 | Windstorm | La Nina Winter Windstorms |
| April 22, 2000 | Tornado | Stanwood |
| Winter 2000 | Snowstorm | Black ice on hills, power lines down in Tulalip. Est app 100 car accidents. |
| January 2006 | Severe Storm | Federal Disaster #1641. Roads blocked, lines down in Tulalip. Flooding at Priest Point. |
| November 2006 | Severe Storm | Federal Disaster #1671 |
| December 2006 | Severe Storm | Federal Disaster #1682 |
| December 2007 | Severe storm | Federal Disaster #1734 |
| December 12 - January 5, 2009 | Snowstorm | Federal Disaster #1825. Record snowfall, roads and businesses closed for 2+ weeks. |
| January 30, 2009 | Severe Storm | Federal Disaster #1817 |

*Table 9: Severe Storm Events in Snohomish County, 1950-2010*

## Location

A severe storm would impact the entire region and all of Tulalip Reservation. Since utility and transportation systems are often the most vulnerable, power and telephone outages are a frequent result of storms and ingress and egress may be limited. Consequently, the more isolated areas of the Reservation may experience greater effects from storms. Severe local storms significantly impact driving conditions on roads, and downed power lines can cause isolation. They can also hinder police, fire, and medical responses to urgent calls.

## Frequency

History shows Snohomish County and the Tulalip Reservation will encounter an average of one major snowstorm every ten years. The frequency of a major snowstorm is variable and is not predictable on a seasonal basis. 2009 was the most recent major snowstorm. Windstorms occur infrequently, but can be predicted more accurately than other storms. The Tulalip

Reservation can expect to experience at least one windstorm each year. **Table 10** describes the likelihood of recurrence for different types of severe storms in Snohomish County.

| Snohomish County Frequency of Severe Storms | |
|---|---|
| **Type** | **Recurrence/Year (>100% - At least 1 occurrence per year)** |
| High Winds | 175% |
| Winter Storms | 57.5% |
| Tornado | 10% |
| Coastal Flooding | 7.5% |

*Table 10: Frequency of Severe Storms in Snohomish County*

## Severity

The effects upon Tulalip Reservation of a strong thunderstorm, tornado, windstorm or ice storm are likely to be similar: fallen trees, downed power lines and interruption of transportation lifelines, damaged homes and public buildings. Fatalities are uncommon in western Washington, but they can occur.

While tornados are rare and localized, they are potentially the most dangerous. Should one strike a populated area, damage could be widespread and fatalities could occur. In the case of extremely high winds some buildings may be damaged or destroyed.

The effects of an ice storm or snowstorm are downed power lines and trees and a large increase in traffic accidents. While over 85% of ice storm deaths are caused by traffic accidents, storms can also cause death by exposure, heart failure due to shoveling or other strenuous activity, and carbon monoxide poisoning. Other concerns include roof collapses due to heavy snow loads and frozen pipes.

Although windstorms are not a frequent problem on the Tulalip Reservation, they have been known to cause substantial damage.

## Warning Time

A meteorologist can often predict the likelihood of an onset of a severe storm. This can give several days of warning time, however, meteorologists cannot predict the exact time of onset or the severity of the storm. Some storms may come on more quickly and have only a few hours of warning time.

## Secondary Hazards

The most significant secondary hazards to severe local storms are floods, landslides and electrical hazards (fires) from downed power lines. Rapidly melting snow combined with heavy rain can overwhelm both natural and man-made drainage systems, causing overflow and property destruction. Landslides occur when the soil on slopes becomes oversaturated and fail.

# *Exposure Inventory*

## Loss Estimation

Currently there are no standards in place to estimate losses from severe weather. Severe weather has the potential to affect all people, property and infrastructure, but in most cases, it is infrastructure, such as power lines, that suffer the most damage from severe weather, such as high winds and ice. The values used in this loss estimation are a hypothetical estimate of all potential damage.

## Vulnerability

Marine Drive is most vulnerable to severe weather. It is that main road on the Reservation and critical for emergency responders to use. It is also prone to downed trees and black ice, which cause numerous accidents.

Also vulnerable are the many homes located on narrow, dirt paved and usually one-laned roads, some of which pass through steep slopes known to experience landslides or washouts. This isolation can prevent ingress or egress, and may prevent emergency responders from accessing many homes.

*Assumptions*

- Damage to improvements of a parcel (that is, the building) is estimated to be 5%
- Content loss is 10% of half of the improvement value.

| Severe Storms | Improvements | | | Land / Buildings | | Contents | | | Daily Sales | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Exposed | | Damage | Exposed | | Exposed | | Damage | | |
| Parcels | $490.9 M | 100% | $24.5 M | $736.0 M | 100% | $245.4 M | 100% | $24.5 M | | |
| Critical Buildings | $335.5 M | 100% | $16.8 M | 157 | 100% | $354.1 M | 100% | $35.4 M | $882 K | 100% |

| Severe Storms | At Risk | % of Total |
|---|---|---|
| Population | 9246 | 100% |
| Vulnerable Population | 1069 | 100% |