

TSUNAMI and SEICHE

DEFINITIONS:

Seiche – The action of a series of standing waves (sloshing action) of an enclosed body or partially enclosed body of water caused by earthquake shaking. Seiche action can affect harbors, bays, lakes, rivers, and canals.

Tsunami – A sea wave of local or distant origin that results from large-scale displacements of the seafloor associated with large earthquakes, major submarine slides, or exploding volcanic islands.

BACKGROUND INFORMATION:

Tsunami

The Pacific Coast of Washington is at risk from tsunamis. These destructive waves can be caused by coastal or submarine landslides or volcanism, but they are most commonly caused by large submarine earthquakes.



Tsunamis are generated when these geologic events cause large, rapid movements in the sea floor that displace the water column above. That swift change creates a series of high-energy waves that radiate outward like pond ripples. Offshore tsunamis would strike the adjacent shorelines within minutes and also cross the ocean at speeds as great as 600 miles per hour to strike distant shores. In 1946, a tsunami was initiated by an earthquake in the Aleutian Islands of Alaska; in less than 5 hours, it reached Hawaii with waves as high as 55 feet and killed 173 people.

Tsunami waves can continue for hours. The first wave can be followed by others a few minutes or a few hours later, and the later waves are commonly larger. The first wave to strike Crescent City, California, caused by the Alaska earthquake in Prince William Sound in 1964, was 9 feet above the tide level; the second, 29 minutes later, was 6 feet above tide, the third was about 11 feet above the tide level, and the fourth, most damaging wave was more than 16 feet above the tide level. The third and fourth waves killed 11 people. Estimates of the damage range from \$7.4 million to \$16 million (in 1964 dollars). That same tsunami destroyed property in many areas along the coast from Alaska to California. In Washington alone, that tsunami caused \$105,000 (in 1964 dollars) in damage.

That 1964 event was the most recent significant tsunami to reach the Washington coast, but recent geologic investigations indicate that large tsunamis have struck our coast many times in the last few thousand years.

On the Pacific Coast, from southern British Columbia to northern California, people and property are at risk both from distantly and locally generated tsunamis. Recent studies indicate that about a dozen very large earthquakes (with magnitudes of 8 or more) have occurred in the Cascadia Subduction Zone. Computer models indicate that tsunamis waves generated by an earthquake of this magnitude occurring within the Cascadia Subduction Zone might range from 5 to 55 feet in height and could affect the entire coastal region of Washington State.

Seiche

In the majority of instances, earthquake-induced seiches do not occur close to the epicenter of an earthquake, but hundreds of miles away. This is due to the fact that earthquake shockwaves close to the epicenter consist of high-frequency vibrations, while those at much greater distances are of lower frequency. These low frequency vibrations can enhance the rhythmic movement in a body of water; the largest seiches develop when the period of ground shaking matches the frequency of oscillation of the body of water.

HISTORY:

Tsunami

There is no written historical record of a damaging tsunami occurring in or affecting Skagit County.

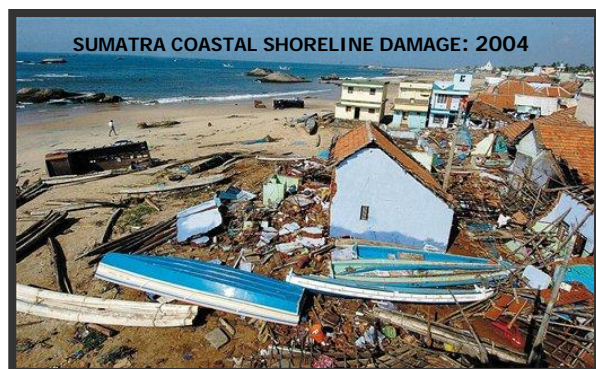
Geologic evidence of tsunamis has been found at Cultus Bay on Whidbey Island and at West Point in Seattle. Researchers believe these tsunami deposits are evidence of earthquake activity along the Seattle Fault or other shallow crustal faults located in the Puget Sound area.

While tsunamis can occur anywhere in the world, they occur more frequently in the Pacific Ocean. Areas that have recently been affected by Pacific Ocean tsunamis are: Peru, August, 2007; Solomon Islands, April, 2007; Kuril Islands, January, 2007 and November, 2006.

The most damaging tsunami on record occurred in the Indian Ocean on December 26, 2004. A summary of that event, as well as other recent tsunami events are listed below.

2004, Indian Ocean; Sumatra

On December, 26, 2004, a massive earthquake measuring over 9.0 (Richter) occurred under the Indian Ocean floor just off the coast of the Indonesian island of Sumatra. Violent movement of the Earth's tectonic plates in this area displaced an enormous amount of water, sending powerful tsunami waves in every direction. Within hours, tsunami waves radiating from the earthquake's epicenter slammed into the coastline of 12 Indian Ocean countries with wave heights reaching up to 50 feet. As many as 250,000 persons were either killed or listed as missing and presumed dead. As many as 1,125,000 people were displaced by the earthquake and subsequent tsunami. The economic losses exceed \$10 billion.



1998, Pacific Ocean; New Guinea

On July 17, 1998, an earthquake measuring 7.1 (Richter) occurred about 15 miles off the coast of New Guinea in the southwestern Pacific Ocean. While the magnitude of the quake was not large enough to create the tsunami directly, it is believed the earthquake generated an undersea landslide, which in turn caused the tsunami that generated waves reaching 40 feet killing an estimated 2,200 people.

1976, Pacific Ocean; Philippines

On August 16, 1976, an earthquake measuring approximately 7.6 (Richter) occurred in the Moro Gulf near Philippine island of Mindanao. While the earthquake caused widespread damage, its effect paled in comparison to the massive tsunami it helped create that devastated 700 kilometers of coastline and killed over 5,000 people.

1964, Pacific Ocean; West Coast of North America and Hawaii

On March 28, 1964, the Alaska Earthquake occurred in Prince William Sound and measured 9.2 (Richter). This earthquake generated multiple tsunamis that were recorded throughout the Pacific. The most disastrous tsunami to hit the west coast of the contiguous United States and British Columbia, Canada was from this earthquake. A wave height of approximately 200 feet was recorded in Valdez Inlet (the wave height at Ocean Shores, Washington was approximately 10 feet) and a total of 123 people were killed as a result of the tsunami in Alaska, British Columbia, Oregon, and California. While Washington received minor damage as a result of this tsunami, damages totaled \$84 million in Alaska, \$10 million in British Columbia, \$700,000 in Oregon, and \$10 million in California.

1960, Pacific Ocean; Chile and other Pacific Nations

On May 22 1960, the biggest earthquake ever recorded at the time occurred just off the coast of Chile, South America. The earthquake measured 9.5 (Richter) with swarms of aftershock earthquakes that measured as large 8.0 (Richter). The earthquakes triggered the creation of a tsunami, which was responsible for most of the ensuing devastation and death.

The tsunami, together with the coastal subsidence and flooding, caused tremendous damage along the Chile coast, where about 2,000 people died. The waves spread outwards across the Pacific and fifteen (15) hours after the earthquake, tsunami waves flooded Hilo, on the island of Hawaii, where they built up to thirty (30) feet in height and caused 61 deaths along the waterfront. Seven hours later, the waves flooded the coastline of Japan where waves at least ten (10) feet in height caused 200 deaths. Tsunami waves also caused damage in the Marquesas, Samoa, and New Zealand.

Seiche

Puget Sound has experienced seiches at various times in the past. In 1891, an earthquake near Port Angeles caused an 8-foot seiche in Lake Washington. Seiches generated by the 1949 Queen Charlotte Islands earthquake were reported on Lake Union and Lake Washington. The 1964 Alaska Earthquake created seiches on 14 inland bodies of water in Washington State.

More recently, a 7.9 (Richter) magnitude earthquake that occurred on November 3, 2002 near Denali National Park in Alaska created minor seiche action on Lake Union in Seattle causing minor damage to several houseboat dock moorings.

HAZARD IDENTIFICATION:

As stated earlier ... there is no written historical record of a damaging tsunami occurring in or affecting Skagit County.

However, recent scientific studies conclude that tsunami inundation resulting from a large-magnitude Cascadia Subduction Zone earthquake does pose a hazard to some areas of Skagit County.

If a tsunami were to strike the coast of Washington and Vancouver Island in such a way that a portion of the tsunami directly enters the Strait of Juan de Fuca, a large tsunami wave could travel easterly thereby directly striking the west shore of Whidbey Island (Island County) and would most likely also impact the west shore of Fidalgo Island portions of the City of Anacortes, and other low-lying shoreline areas within Skagit County.

In addition to the direct impact of the tsunami, such an event could produce extensive seiche action of nearby waters resulting in additional damage to nearby shoreline areas not directly impacted by the tsunami.

The first warning sign of a coming tsunami generated from the Cascadia Subduction Zone may be a large magnitude 8 (Richter) mega-thrust earthquake with ground shaking possibly lasting as long as 3 minutes. An earthquake of this magnitude would present all of the typical problems associated with a large earthquake but these problems could be compounded in low-lying shoreline areas of Skagit County due to tsunami and/or seiche action.

Studies indicate that about a dozen very large earthquakes with magnitudes of 8 (Richter) or more have previously occurred in the Cascadia Subduction Zone off the coast of Washington. Computer models indicate that tsunami waves from such an event could be up to 30 feet in height and could affect the entire coast of Washington. Such a tsunami would most likely impact the Pacific coastal areas of Washington but inlets like the Strait of Juan de Fuca, could also be impacted.

The ***Tsunami Hazard Map of the Anacortes-Whidbey Island Area, Washington*** was produced in January, 2005, by the Washington State Department of Natural Resources, Division of Geology and Earth Resources in cooperation with the Washington State Military Department, Emergency Management Division. This map is the result of an extensive computer modeling study conducted by the Center for the Tsunami Inundation Mapping Efforts (TIME) at the National Oceanic and Atmospheric Administration (NOAA) Pacific Marine Environmental Laboratory in Seattle, Washington.

The ***Tsunami Hazard Map of the Anacortes-Whidbey Island Area, Washington*** is considered a benchmark document and was used to develop both the hazard identification and vulnerability assessment sections of this document.

For further information regarding the above-referenced study and to view the map, go to:

<http://www.dnr.wa.gov/geology/pdf/ofr05-1.pdf>

According to the above-referenced study, a tsunami induced by a Cascadia Subduction Zone earthquake could generate waves of sufficient height to inundate various shoreline and adjacent low-lying areas of Skagit County with water up to 2 meters in depth. Certain isolated shoreline areas could receive water greater than 2 meters in depth.

Areas with possible inundation depths of 2 meters or less:

- Fir Island
- Swinomish Channel
- Snee-oosh Beach
- Similk Bay
- Dewey Beach
- Western shoreline of Fidalgo Island
- Guemes Channel
- Easterly shoreline of Guemes Island
- Cypress Island – Strawberry Bay and Secret Harbor
- Fidalgo Bay
- March Point
- Padilla Bay
- Bay View
- Samish Flats north of Joe Leary Slough
- Samish Island – Camp Kirby & Blue Heron Beach
- Samish Bay
- Edison

Areas with possible inundation depths greater than 2 meters:

- Bowman's Bay
- Rosario Beach
- Biz Point
- Alexander Beach
- Skyline
- Allen Island
- Burrows Island
- Fidalgo Head and Washington Park
- West Beach, Guemes Island
- Eastern shoreline of Fidalgo Bay near Anacortes Marina
- Southern shoreline of Padilla Bay

NOTE: The following excerpt is included in the results comments of the study ...

“ ... Large areas of inundation occur in areas of low topography surrounding Samish Bay, Padilla Bay and the Swinomish Channel. Though not part of the modeling study, inundation also occurs within the vicinity of Fir Island. These areas are protected by salt-water dikes that were not resolved in the grid used for the modeling, but the height of the dikes suggest they would be overtopped by the model tsunami and so inundation shown there is probably important ... ”

VULNERABILITY ASSESSMENT:

While the Pacific coastline is most vulnerable to tsunamis generated either at a distance or by a local subduction or crustal zone (shallow) earthquake, the inland waters on the Strait of Juan de Fuca are also vulnerable to tsunamis but less so than the coastal areas.

Within Skagit County, those areas listed on the preceding page have the greatest vulnerability to possible tsunami and seiche events. In addition, those properties immediately adjacent to the many lakes within Skagit County could also be vulnerable to seiche action.

When considering tsunami hazard vulnerability, it should be noted that local tides will have a strong influence on the magnitude of a tsunami. A tsunami or seiche event occurring at high tide will no doubt be more damaging than an event occurring at low tide. While the study did not take into consideration the salt-water dikes in many areas along local shorelines, it is logical to think these structures should at least partially mitigate the effects of a tsunami or seiche for those areas protected by salt-water dikes.

In addition to the tremendous hydraulic force of the tsunami waves themselves, floating debris carried by a tsunami can endanger human lives and damage structures. Ships moored at piers and in harbors may be swamped and sunk or left battered and stranded high on the shore. Breakwaters and piers could collapse due to the sheer impact of the waves or because of severe scouring actions that sweep away their foundation materials.

Within Skagit County, government-owned infrastructure owned by the Port of Anacortes and the Port of Skagit County as well as the Washington State Department of Transportation Anacortes Ferry Terminal may be vulnerable to tsunami. In addition, the numerous marina facilities as well as the downtown commercial and industrial/manufacturing areas of the City of Anacortes and the Town of La Conner could be vulnerable to tsunami or severe seiche action.

A tsunami or severe seiche action would most likely cause damage to agricultural crops and washing or erosion of farm ground located near shoreline areas throughout the Skagit Delta, especially in those areas near Samish Bay, Padilla Bay, and Skagit Bay.

PROBABILITY and RISK:

Considering: there have been no recorded damaging tsunami or seiche events within Skagit County; the primary cause of a damaging tsunami impacting Skagit County is from a large magnitude Cascadia Subduction Zone earthquake; that such events have a historical frequency of occurrence rate averaging between 500 and 540 years; that if such an earthquake were to occur, the Center for the Tsunami Inundation Mapping Efforts has identified only a few areas in Skagit County that could receive possible inundation depths greater than 2 meters; and that the Center for the Tsunami Inundation Mapping Efforts did not take into considerations existing local salt-water dikes in their inundation study ... there is a **low probability** of a tsunami or seiche event impacting Skagit County and therefore, there is a **low risk** to persons and/or property within Skagit County due to tsunami and/or seiche events.

CONCLUSION:

Should a tsunami or seiche event impact Skagit County, shoreline and nearby low-lying areas would be most seriously impacted.

For tsunamis generated by local events such as a Cascadia Subduction Zone event, the time of arrival could be less than two hours. The shaking of an earthquake may be the only warning residents have of an impending tsunami. For tsunamis generated at a distance, local communities should be able to take preventive action to evacuate persons if warning is received early enough (two to five hours) prior to the arrival of the tsunami.

Even though there is a low probability of a tsunami or seiche event impacting Skagit County and a low risk to persons and/or property within Skagit County due to tsunami and/or seiche events, there are a few basic actions local government could take to help prevent loss of life should such an event occur. These actions include:

1. The establishment and maintenance of a comprehensive tsunami public educational program to keep the public informed of the danger and of steps to be taken for personal protection.
2. The placement of tsunami hazard informational signs in parks and other public areas that have been identified as being vulnerable to tsunami inundation to alert visitors of the hazard and provide information as to what actions they should take to avoid tsunami. In some areas, it may be useful to identify and sign tsunami evacuation routes.