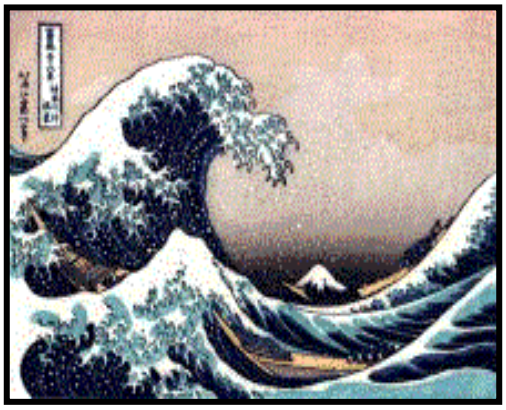
TSUNAMI and SEICHE

DEFINITIONS:

Seiche – 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 Japanese word that means *harbor wave*; a sea wave of local or distant origin that results from large-scale seafloor displacements associated with large earthquakes, major submarine slides, or exploding volcanic islands.

BACKGROUND INFORMATION:

Tsunami

The phenomenon we call "tsunami" (soo-NAH-mee) is a series of traveling ocean waves of extremely long length. A tsunami can be generated when there is significant vertical movement of the seafloor over a large area, typically caused by large earthquakes occurring below or near the ocean floor. Earthquakes occurring at plate boundaries beneath the ocean, especially subduction earthquakes are particularly effective in generating tsunamis. Underwater volcanic eruptions and landslides can also generate tsunamis.

Large Pacific Ocean tsunamis typically have wave crest to wave crest distances of 60 miles and can travel about 600 miles per hour in the open ocean. A tsunami can traverse the entire 12,000 to 14,000 miles of the Pacific Ocean in 24 hours, striking land with great force. In the deep ocean, the length from wave crest to wave crest may be a hundred miles or more but with a wave height of only a few feet or less. They cannot be felt aboard ships nor can they be seen from the air in the open ocean. In deep water, the waves may reach speeds exceeding 500 miles per hour. Despite the great size of the Pacific Ocean, which covers more than a third of the Earth's total area, tsunami waves can traverse the Pacific's entire basin in 20 to 25 hours. A tsunami becomes a hazard as the wave or waves approach land and the ocean depths decease causing the wave or waves to "feel bottom" and "grow in height" above the surface of the ocean as they reach shore. Tsunamis 10 to 20 feet high have the potential to be very destructive and cause damage to structures as well as injuries or deaths; large tsunamis have been known to rise over 100 feet in height.

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 or seiche occurring in 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.

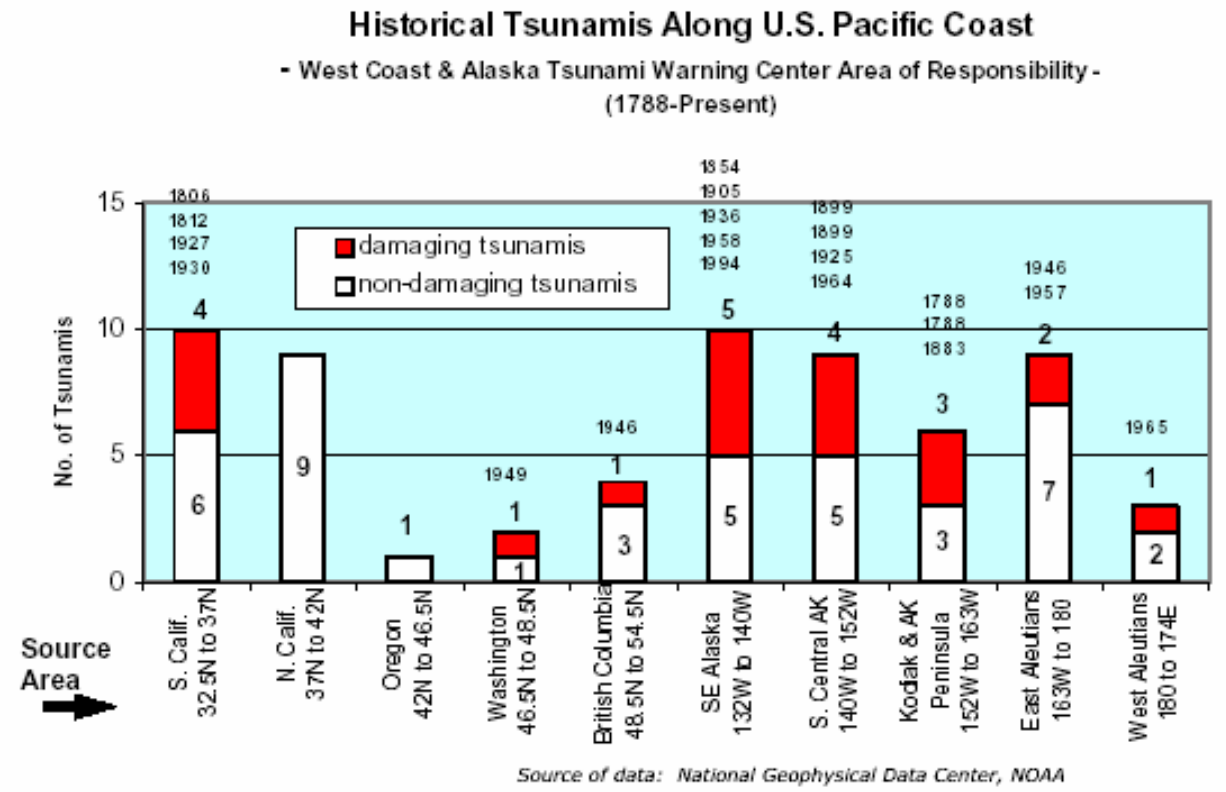
The 1964 Alaska Earthquake generated multiple tsunamis that were recorded throughout the Pacific. The most disastrous tsunami to hit the west coast of the contiguous United States and British Columbia, Canada was from this earthquake. A wave height of approximately 200 feet was recorded in Valdez Inlet (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.

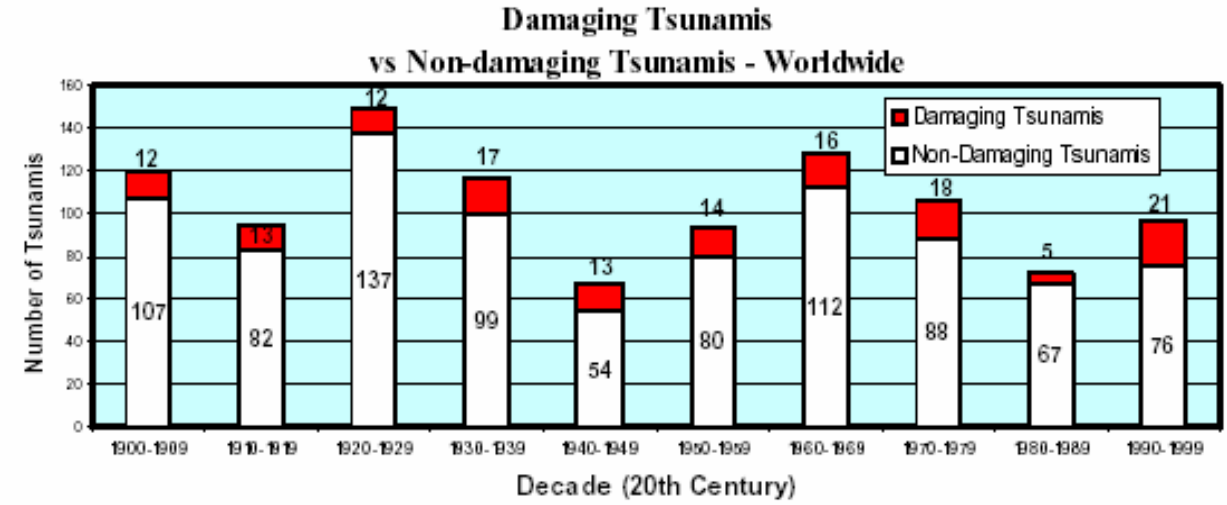
On May 7, 1986, an earthquake measuring 7.7 (Richter) occurred in the Aleutian Islands near Adak, Alaska that generated a tsunami. People living in shoreline areas throughout western Washington were alerted as to the possible danger of a tsunami and between 2,000 and 3,000 Skagit County residents fled their homes in low-lying shoreline areas to safer areas on higher ground. While wave heights varied between 3 and 4 feet in communities on the Washington coast and the westerly shore of Vancouver Island, water levels rose only a few inches in the Anacortes and La Conner areas.

From 1992 to 1996, over 2,000 people were killed by tsunamis occurring in Nicaragua, Indonesia, Japan, the Philippines, and Peru with property damage totaling nearly one billion U.S. dollars.

The largest recorded earthquake (magnitude 9.5 Richter) struck just off the coast of Chile in May 1960. This earthquake generated a tsunami that caused destruction throughout the Pacific Ocean including Japan and Hawaii. Much of the damage occurred in Hilo, Hawaii where 61 people were killed and damages totaled over $23 million. This earthquake occurred along a subduction fault where the ocean floor is being pushed beneath the continental land mass. It is important to note that this same plate tectonic setting is found off the coast of southern British Columbia, Washington, Oregon, and northern California. Historically, tsunamis originating in

the northern Pacific and along the west coast of South America have caused more damage on the west coast of the United States than tsunamis originating in Japan and the southwest Pacific.





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.

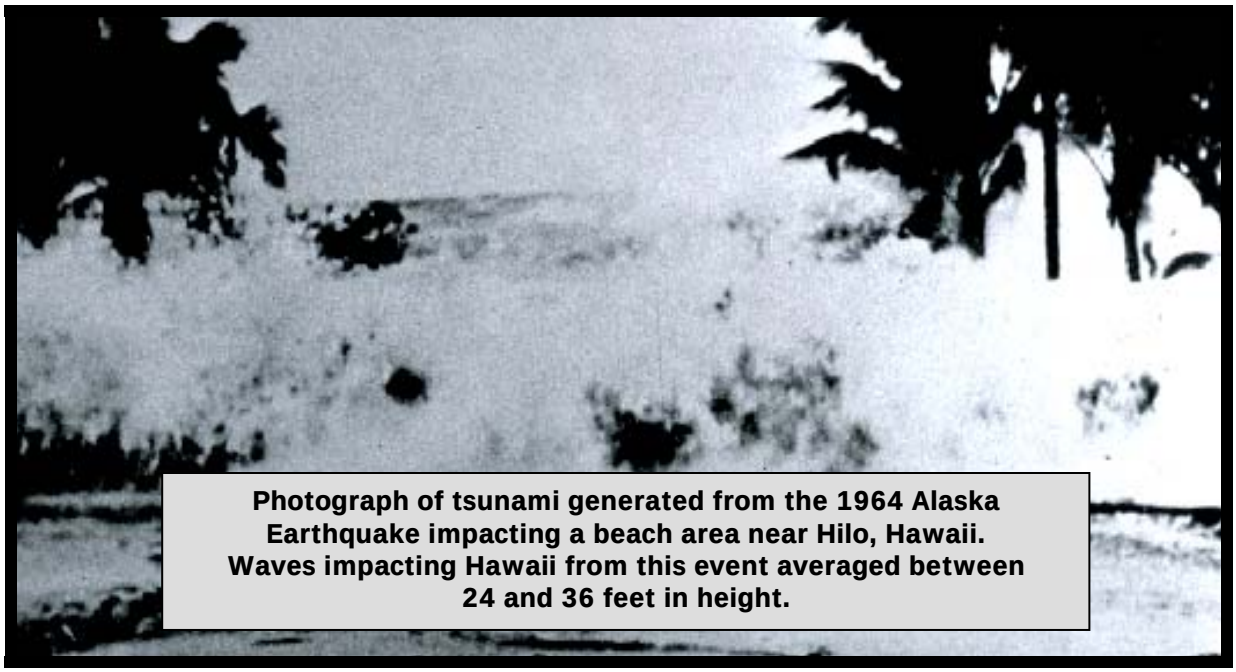
More recently, a 7.9 (Richter) magnitude earthquake that occurred on November 3, 2002 near Denali National Park in Alaska created minor seiche action on Lake Union in Seattle causing minor damage to several houseboat dock moorings.

HAZARD IDENTIFICATION:

While there is no written historical record of a tsunami occurring in Skagit County, scientists have stated that it might be possible for a tsunami to impact Skagit County given a specific set of circumstances.

If a tsunami were to strike the coast of Washington and Vancouver Island in such a way that a portion of the tsunami directly entered 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 most likely impacting the west shore of Fidalgo Island and portions of the City of Anacortes as well.

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



Photograph of tsunami generated from the 1964 Alaska Earthquake impacting a beach area near Hilo, Hawaii. Waves impacting Hawaii from this event averaged between 24 and 36 feet in height.

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. Furthermore, 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 receive a "wall of water". Computer models indicate that locally induced tsunamis from the Cascadia Subduction Zone could generate waves of 6 to 60 feet in height along the Washington Coast. Of particular concern is the possibility of a tsunami generated by a subduction zone earthquake in which the triggering fault could be located at a sufficient distance (i.e., offshore from northern California or northern British Columbia) that Washington coastal residents and tourists would not feel ground shaking. Tsunamis generated by a quake of this size and location may have travel times of an hour or less, and could arrive unannounced.

It is believed that a tsunami generated from an earthquake occurring in Alaska would most likely be less destructive and possibly cause very little damage shoreline areas of Skagit County as evidenced by the previously referenced May 7, 1986 earthquake that occurred near Adak, Alaska.

The following list is a compilation of comments and suggestions made by various stakeholders and the public regarding possible problems that could result from a tsunami or seiche event.

In addition to damaging homes, businesses, property, and the environment, a tsunami or seiche event in Skagit County could potentially result in the following:

- Damage could occur to the Washington State ferry dock, the Skagit County ferry dock, the Port of Anacortes facilities as well as the many marinas and marine-related businesses located in Anacortes.

- Damage could also occur to the Port of Skagit County facilities as well as the many private dock facilities and marine-related businesses located along the Swinomish Channel in La Conner.

- The Shell and Tesoro refinery docks and associated pipelines may be damaged causing a large oil spill to the waters of Fidalgo Bay and Padilla Bay.

- Even with prior notification of a potential event, evacuation of low-lying coastal areas would be very difficult due to the unfamiliarity of such events in Skagit County.

- Salt water dike systems along Skagit Bay, Fidalgo Bay, and Padilla Bay may be damaged and/or destroyed.

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. People and property on or near beaches or located in low-lying areas of coastal towns and cities, near tidal flats or near mouths of rivers draining into the ocean are most vulnerable to the impacts of a large tsunami.

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. Railroad yards and oil tanks situated near shorelines are particularly vulnerable to the impacts of tsunami and seiche. **Local rail transportation may be severely impacted due to the fact that the Sante Fe–Burlington Northern railroad lines are typically located along shoreline areas throughout much of the Puget Sound region**. Large fires fueled by extremely large amounts of flammable liquids from damaged facilities such as oil refineries can cause additional, secondary damage.

Port and other public utilities facilities as well as naval facilities, fishing fleets, and marinas are frequently the backbone of the economy of areas impacted by tsunami and seiche and these are the very resources that generally receive the most severe damage. Until debris can be cleared, wharves and piers rebuilt, utilities restored, and the fishing fleets reconstituted, communities may find themselves without fuel, supplies, and employment. Wherever water transportation is a vital means of supply, disruption of coastal systems caused by tsunami or seiche can have far reaching economic effects.

Those areas that could be vulnerable to tsunami or severe seiche action in Skagit County are:

- The west shoreline of Fidalgo Island.
- Shoreline areas of Guemes Island, Cypress Island, Sinclair Island, and Samish Island.
- Shoreline and adjacent low-lying areas within the City of Anacortes.
- Oil refinery facilities and associated industrial facilities located on March Point.
- Shoreline areas of Fidalgo Bay, Padilla Bay, Bellingham Bay, and Samish Bay.
- Shoreline areas in the Deception Pass, Similk Bay, Hope Island, and Skagit Bay areas.
- The Town of La Conner, the Swinomish Indian Village, and shorelines areas along the Swinomish Channel.
- Shoreline areas located on Big Lake, Campbell Lake, Clear Lake, Lake Cavanaugh, Lake Erie, and Lake McMurray.

While most of these areas are primarily residential in nature, the numerous port and marina facilities as well as the downtown commercial and industrial/manufacturing areas of the City of Anacortes and the Town of La Conner would be especially vulnerable to any tsunami or severe seiche action. Also especially vulnerable are two large oil refineries and an associated chemical plant located on March Pont. In addition, 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.

The tsunami generated by the 1964 Alaska Earthquake that struck Hilo, Hawaii washed every house on the main street facing Hilo Bay across the street smashing them against the buildings on the opposite side of the street. Houses were overturned, railroads ripped from their roadbeds, coastal highways buried, and beaches washed away. The waters off the island were dotted with floating houses, debris, and people. Property damage in Hawaii was $26 million (in 1964 dollars) as a result of this tsunami.

Photograph of tsunami-damaged building at Hilo, Hawaii as a result of the 1964 Alaska Earthquake impacting a beach area near Hilo, Hawaii.

PROBABILITY and RISK:

Considering that there have been no recorded damaging tsunami events within Puget Sound, and no serious damage as a result of recorded seiche events in or around Skagit County, there is a **very low probability** of a tsunami or seiche event impacting Skagit County and therefore, there is a **very low risk** to persons and/or property within Skagit County due to tsunami and/or seiche events.

CONCLUSION:

Skagit County is more likely to be affected by a seiche event due to a large underwater landslide or a local, shallow crustal earthquake that causes severe ground shaking than from a damaging tsunami.

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

Alaska averages a tsunami every 1.75 years and a damaging event every 7 years. On average, the west coast of the United States experiences a damaging tsunami every 18 years.

Geologic evidence shows that the Cascadia Subduction Zone has generated great earthquakes in the past, the most recent about 300 years ago. Large earthquakes also occur at the southern terminus of the Cascadia Subduction Zone in Northern California and near the Oregon border. Any large earthquake has the capability to generate a tsunami or severe seiche action.

Recent studies regarding the potential for a great Subduction zone earthquake off the Washington, Oregon, and Northern California coastlines indicate that local tsunami waves may reach nearby coastal communities within minutes of the earthquake thereby giving little or no time to issue warnings.

In cooperation with the *NATIONAL TSUNAMI HAZARD MITIGATION PROGRAM*, the Center for Tsunami Inundation Mapping Efforts (TIME) is currently conducting a tsunami-modeling project in the eastern portion of the Strait of Juan de Fuca. This mapping project will include the communities of Anacortes as well as Bellingham and Whidbey Island.

It is hoped that when this document is updated in 2008, enough reliable information will have been compiled from the above-referenced mapping project to develop a more complete hazard analysis and risk assessment regarding tsunami and seiche hazard for Skagit County.