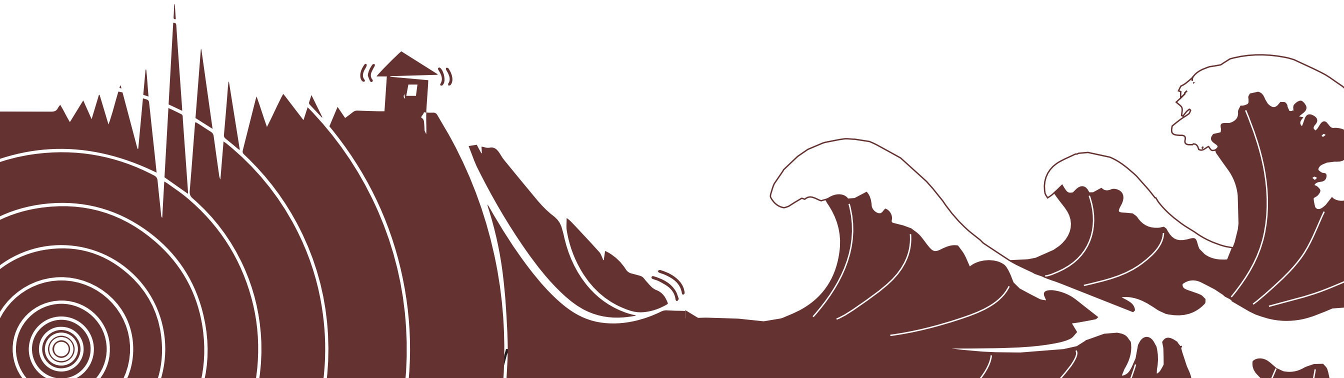
Geologic Risk
for Washington State

WASHINGTON GEOLOGICAL SURVEY

LANDSLIDES, VOLCANOES, EARTHQUAKES, AND TSUNAMIS POSE SERIOUS THREATS TO WASHINGTON'S ECONOMY. WHETHER THEY HAPPEN NEXT YEAR OR IN 50 YEARS, LOSSES ARE LIKELY TO BE DEVASTATING, AND UNDERSTANDING OUR RISKS HELPS INCREASE OUR RESILIENCY



GEOLOGIC RISK CAN BE DEFINED AS THE COMBINATION OF HAZARD, VALUE, AND VULNERABILITY [1]

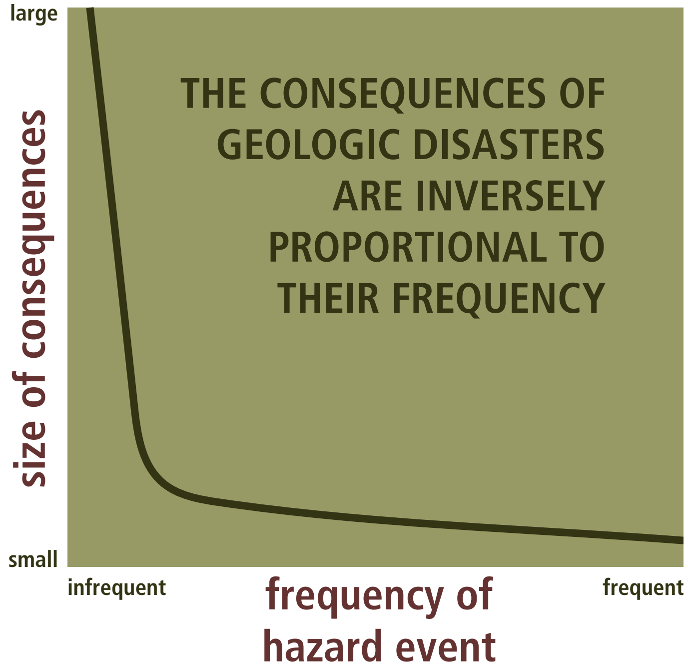
RISK ANALYSIS ANSWERS THREE BASIC QUESTIONS:

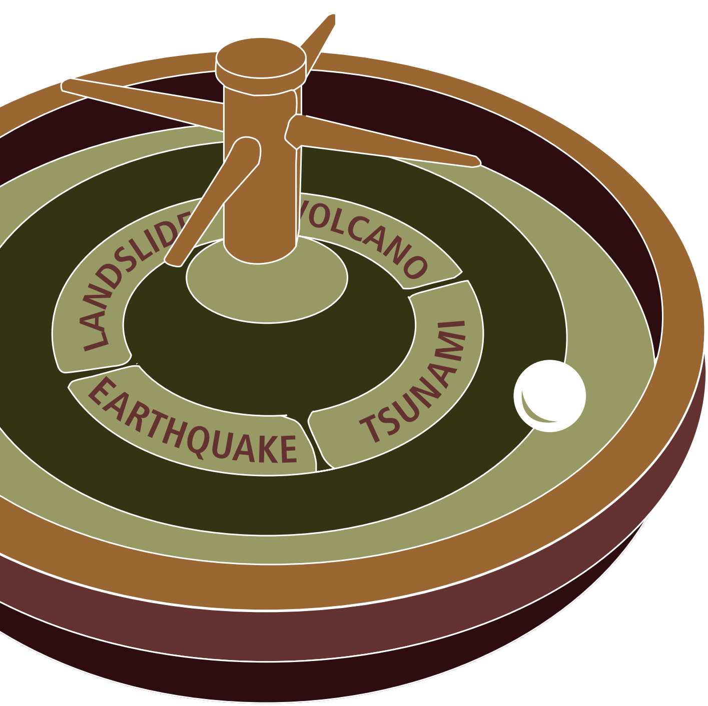
1. What geologic hazards exist in the community?
2. What is the likelihood of hazard events occurring?
3. What are the consequences if the hazard event occurs?

GEOLOGISTS LOOK AT THE GEOLOGIC RECORD TO DETERMINE HOW OFTEN EACH HAZARD IS LIKELY TO OCCUR.

SMALL GEOLOGIC EVENTS HAPPEN FREQUENTLY.

HOWEVER, EVERY FEW HUNDRED YEARS, WE CAN EXPECT ONE OR MORE DISASTROUS EVENTS. THESE LARGE EVENTS HAVE LEFT INDELIBLE MARKS ON THE LANDSCAPE AND OUR LIVES.





IN WASHINGTON STATE, THE MOST SIGNIFICANT GEOLOGICAL HAZARDS ARE **EARTHQUAKES**, **TSUNAMIS**, **VOLCANIC ERUPTIONS**, AND **LANDSLIDES**.

OTHER GEOLOGIC HAZARDS INCLUDE SUBSIDENCE ABOVE IMPROPERLY ABANDONED MINES, RADON, AND OTHER HAZARDOUS MINERAL EXPOSURE.

THE ECONOMIC CONSEQUENCES OF A POTENTIAL GEOLOGIC HAZARD ARE DETERMINED BY CALCULATING THE VALUE OF PROPERTY AND INFRASTRUCTURE IN AREAS LIKELY TO BE AFFECTED BY THAT HAZARD

BENEFIT-COST ANALYSIS

Once the value of loss is known, a benefit-cost analysis may be performed to determine if any mitigation step taken to reduce vulnerability to hazards is an effective use of tax dollars.

HOW IS TOTAL FINANCIAL LOSS CALCULATED?

The total financial worth of a given area is defined as direct loss of people, property, and infrastructure. One could go a step further and add in the monetary value of losses that would occur from disruption of the local or regional economy after a major disaster.

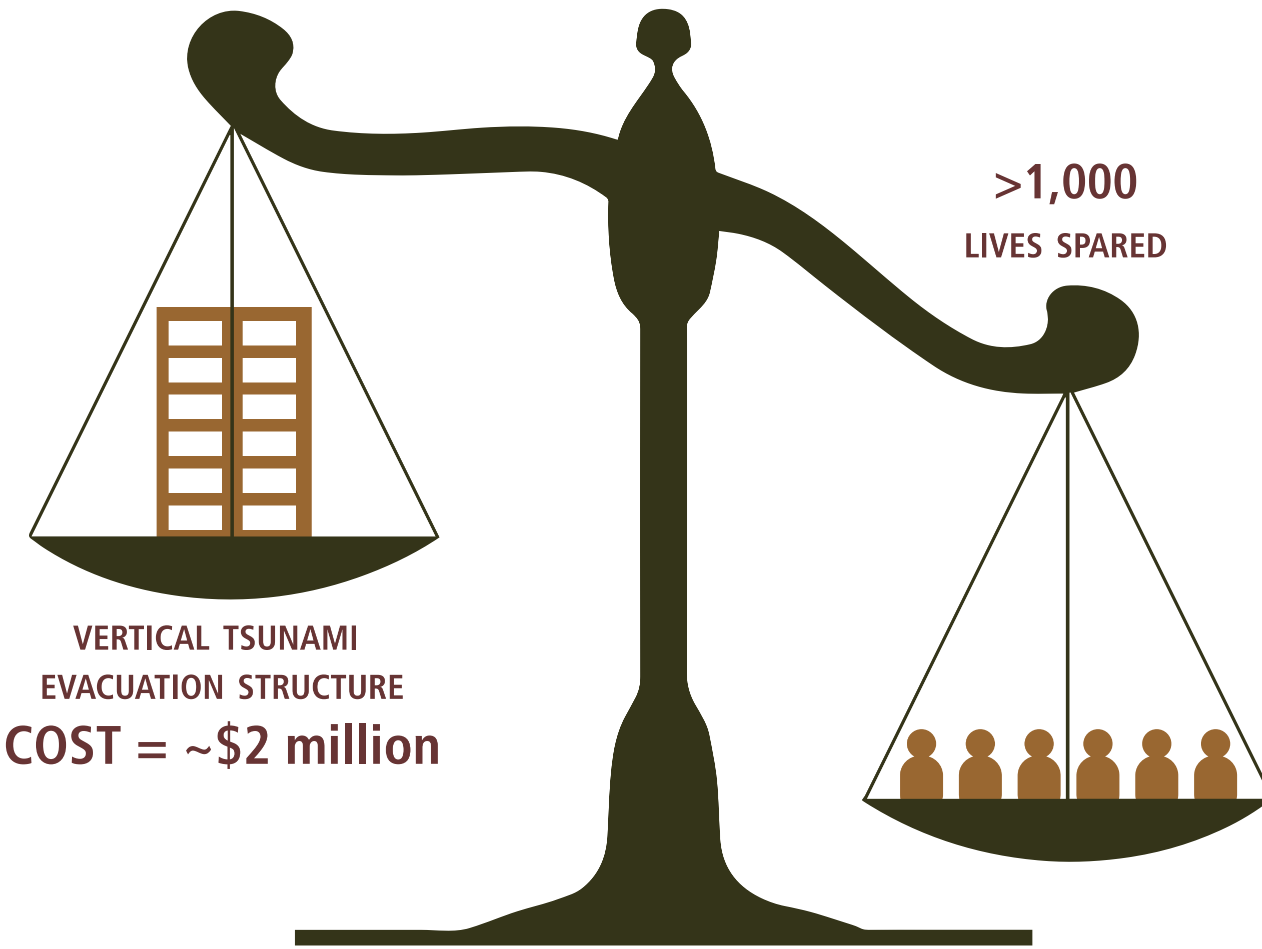
FEMA considers a statistical life to be on average worth $6.3 million. This is the amount FEMA uses in benefit-cost analyses.

GEOLOGIC BENEFIT-COST ANALYSIS IN ACTION:

The Ocosta Elementary School Vertical Tsunami Evacuation Structure

In 2012, Grays Harbor county residents voted on a bond measure to add a vertical tsunami evacuation structure—worth ~$2 million—to the Ocosta Elementary school. The 10,000 square foot structure is designed to be a safe refuge for 1,000 coastal evacuees, where much of the land will likely be inundated during a tsunami from which escape on foot is extremely challenging.

The benefit-cost analysis for building this structure was simple, as the low cost was easily outweighed by the lives that will be saved by its construction. Additional vertical evacuation structures in coastal communities in Pacific County are now in the the planning stages.



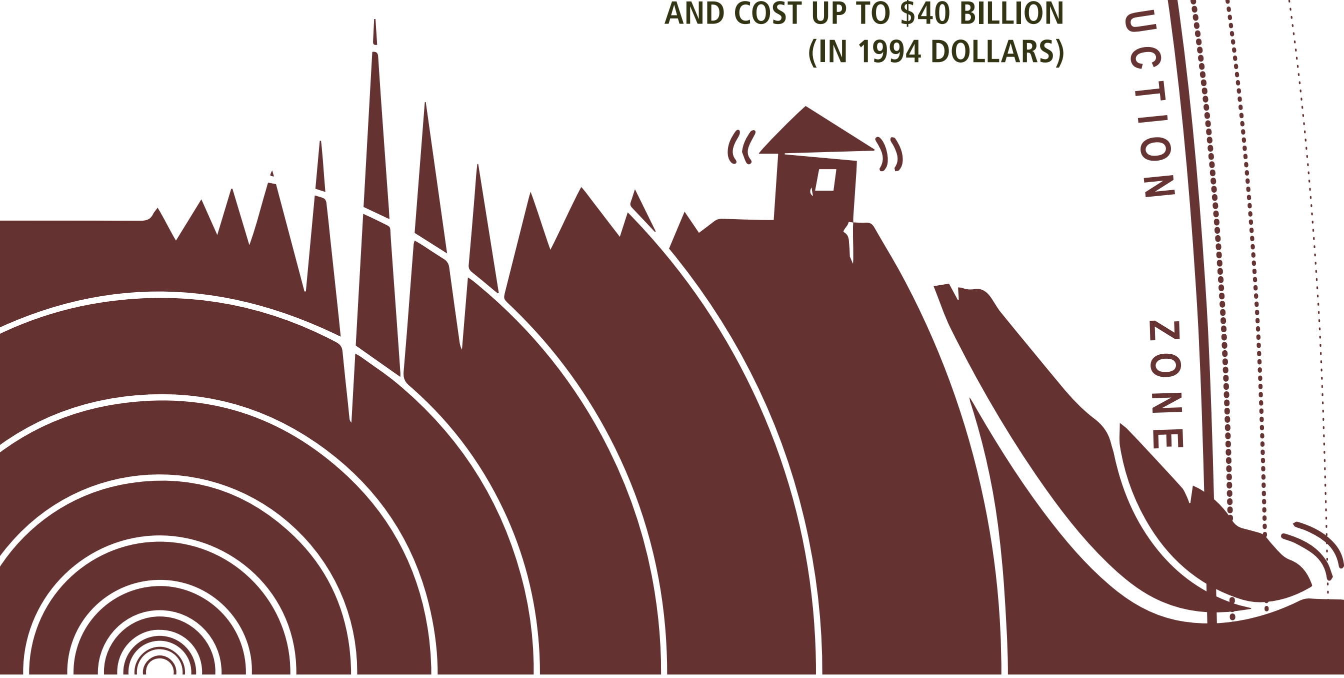
WASHINGTON STATE IS RANKED SECOND IN TERMS OF SEISMIC RISK IN THE NATION

Washington has a high earthquake hazard and has experienced ~15 earthquakes that have caused building damage since 1872. Additionally, geologic evidence demonstrates substantial hazard from faults that have not ruptured since European settlement of the Pacific Northwest. Many of these faults are capable of earthquakes larger than magnitude (M)6.5 at shallow—and therefore highly damaging—depths.

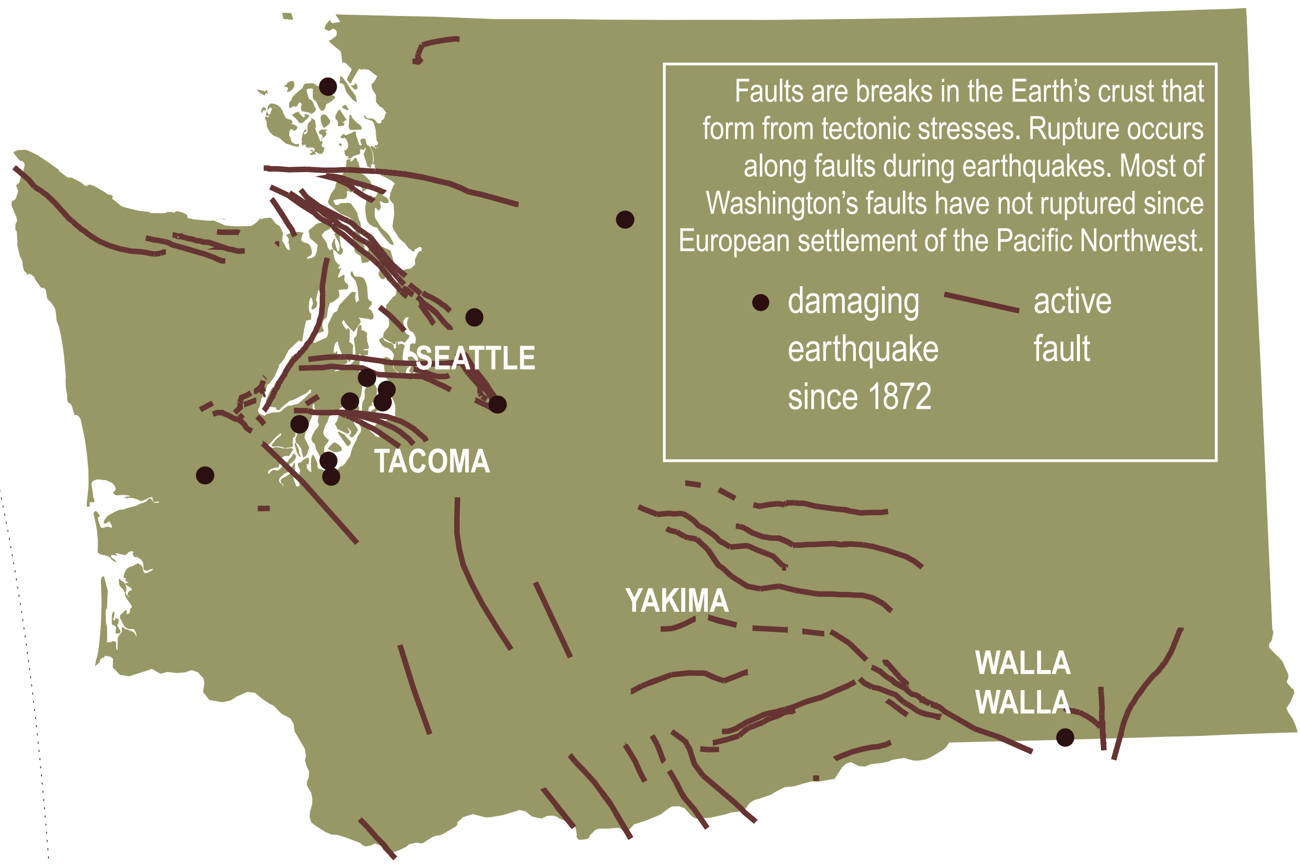
An earthquake scenario for the Seattle Fault shows estimated losses for a M6.7 event would be about **$33 billion**. [2]

Additionally, there is substantial evidence that the Cascadia subduction zone is active and has generated earthquakes greater than M9.0. [3]

THE 1994 M6.7 NORTHRIDGE, CA EARTHQUAKE KILLED 60 PEOPLE AND COST UP TO $40 BILLION (IN 1994 DOLLARS)



61,420 WASHINGTONIANS LIVE IN AREAS HIGHLY VULNERABLE TO LIQUEFACTION DURING AN EARTHQUAKE



FOR WASHINGTON STATE, THE IMPACT OF A M9.0 CASCADIA SUBDUCTION ZONE EARTHQUAKE HAS BEEN ESTIMATED AT $49 BILLION [4]

EARTHQUAKES ON THE CASCADIA SUBDUCTION ZONE RECUR ON AN AVERAGE OF EVERY 500 YEARS OR SO.

THE LAST OCCURRED IN AD 1700, BUT MAJOR QUAKES CAN RECUR EVERY 200 TO 1,000 YEARS.

Washington has a moderate hazard of distantly generated tsunamis. The tsunami associated with the 1964 M9.2 Alaska earthquake was the largest historic event in Washington. Damage estimates were more than $775,000 to homes and bridges and more than $1.5 million (both in 2016 dollars) to oyster beds in sparsely populated Willapa Bay.

Tsunamis generated locally pose a much greater hazard, both because they arrive quickly and because they can be much larger than distantly generated tsunamis—as high as 50 feet in some areas.

Geologic evidence demonstrates that a tsunami was generated by an earthquake on the Seattle fault about 1,000 years ago.

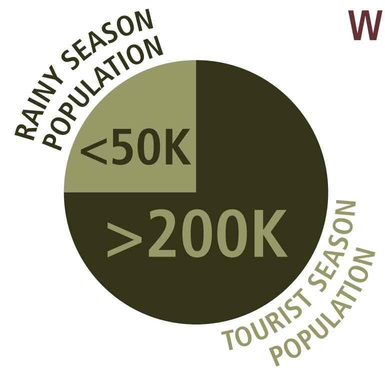
The largest tsunami in Washington in the last 500 years was generated on the Cascadia subduction zone on January 26, 1700. Sand sheets deposited by it are found from British Columbia to northern California, and it was recorded in both Native American and Japanese records.[3]

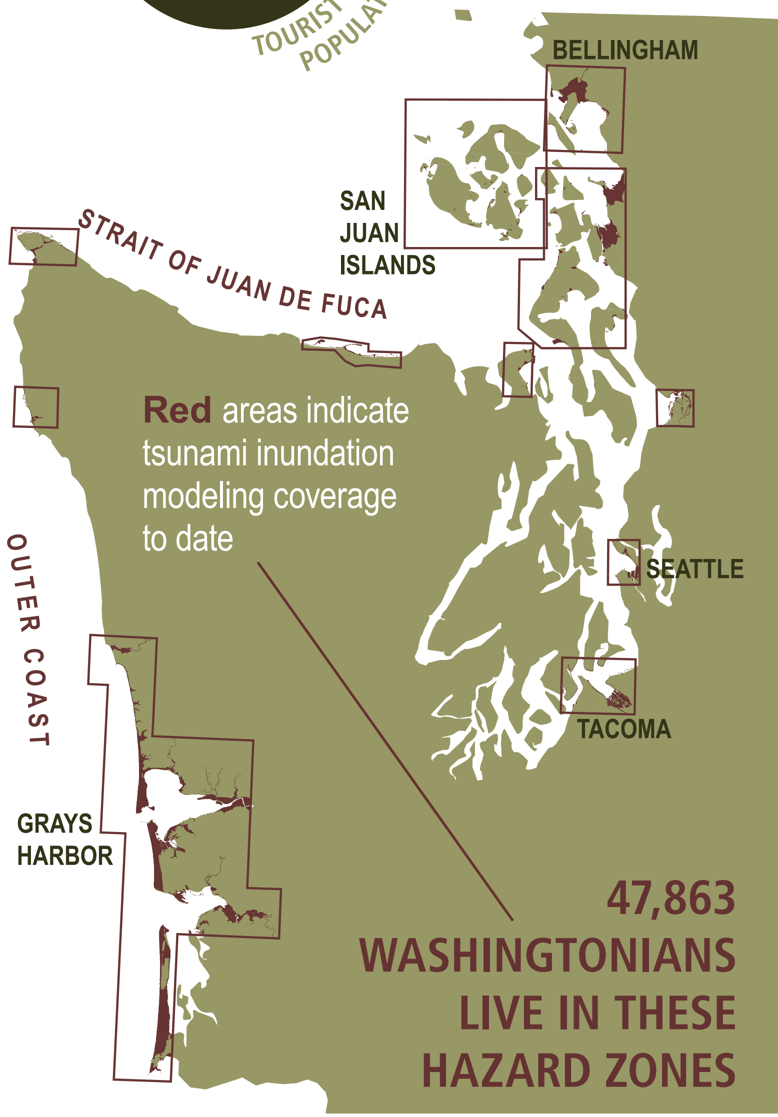
2011 TOHOKU TSUNAMI

~$300 billion in total damages
15,894 fatalities

TSUNAMI RISK CHANGES WITH THE SEASONS

as coastal populations increase dramatically in summer months





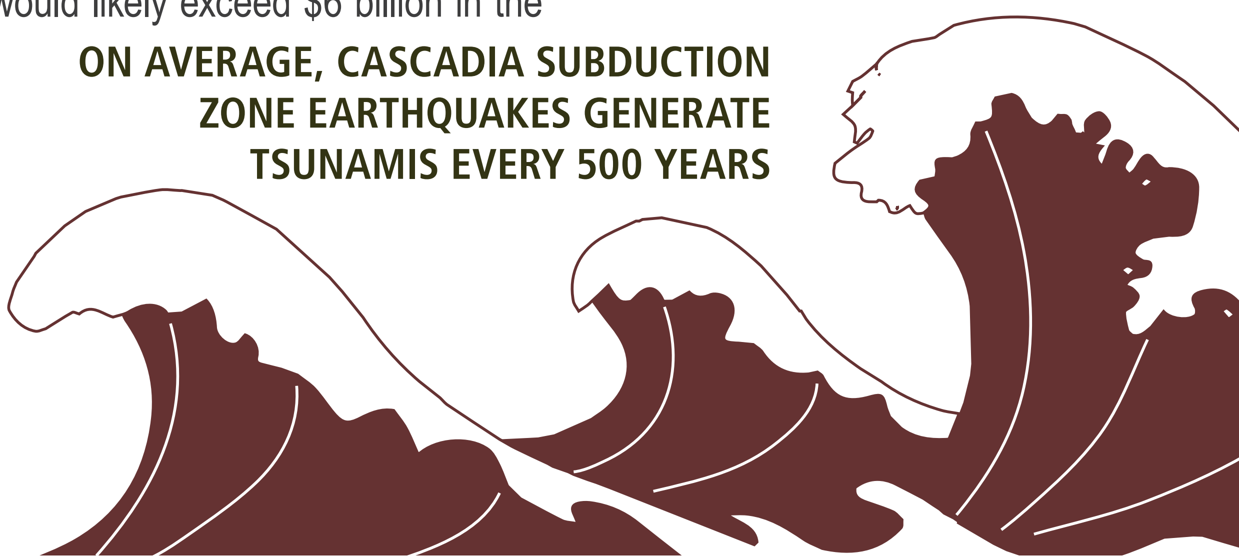
47,863 WASHINGTONIANS LIVE IN THESE HAZARD ZONES

A TSUNAMI IN THE SEATTLE AREA FROM A SEATTLE FAULT EARTHQUAKE HAS A RECURRENCE INTERVAL OF ~2,500 YEARS [2]

The assessed value in the tsunami inundation zone along the outer coast and the Strait of Juan de Fuca is ~$4.5 billion, and businesses in the zone generate $4.6 billion in annual sales volume. [11] Fragility curves (the damage vulnerability of buildings for a geologic event) have yet to be developed for tsunamis, but the state of Oregon has adopted 25% of total value for its damage estimates. That would suggest ~$1 billion in property losses and a total loss of business revenue generated there. Total economic losses in Washington would likely exceed $6 billion in the first year. Loss is compounded when considering that ground subsidence accompanying these events takes several decades to rebound, significantly delaying any rebuilding.

Loss of life in a tsunami depends largely upon time of year, time of day, and citizen response. A reasonable estimate for fatalities during a Cascadia subduction zone tsunami is 10,000. FEMA's benefit-cost model currently assumes the Value of a Statistical Life of $6.3 million, yielding an estimated loss of $63 billion from loss of life alone.

ON AVERAGE, CASCADIA SUBDUCTION ZONE EARTHQUAKES GENERATE TSUNAMIS EVERY 500 YEARS



- **~1500** Bonneville Landslide; blocked Columbia River
- **~1700** Cascadia subduction zone earthquake triggered numerous landslides
- **1872** North Cascades earthquake triggered a landslide that dammed the Columbia River
- **1894** Puyallup River delta submarine landslide kills 2, destroys railroad track and roadway
- **1949** Puget Sound earthquake triggers widespread landslides
- **1965** April 29th earthquake near Tacoma triggered 21 landslides within 60 miles of epicenter
- **1980** Mount St. Helens eruption unleashed by largest debris avalanche in recorded history

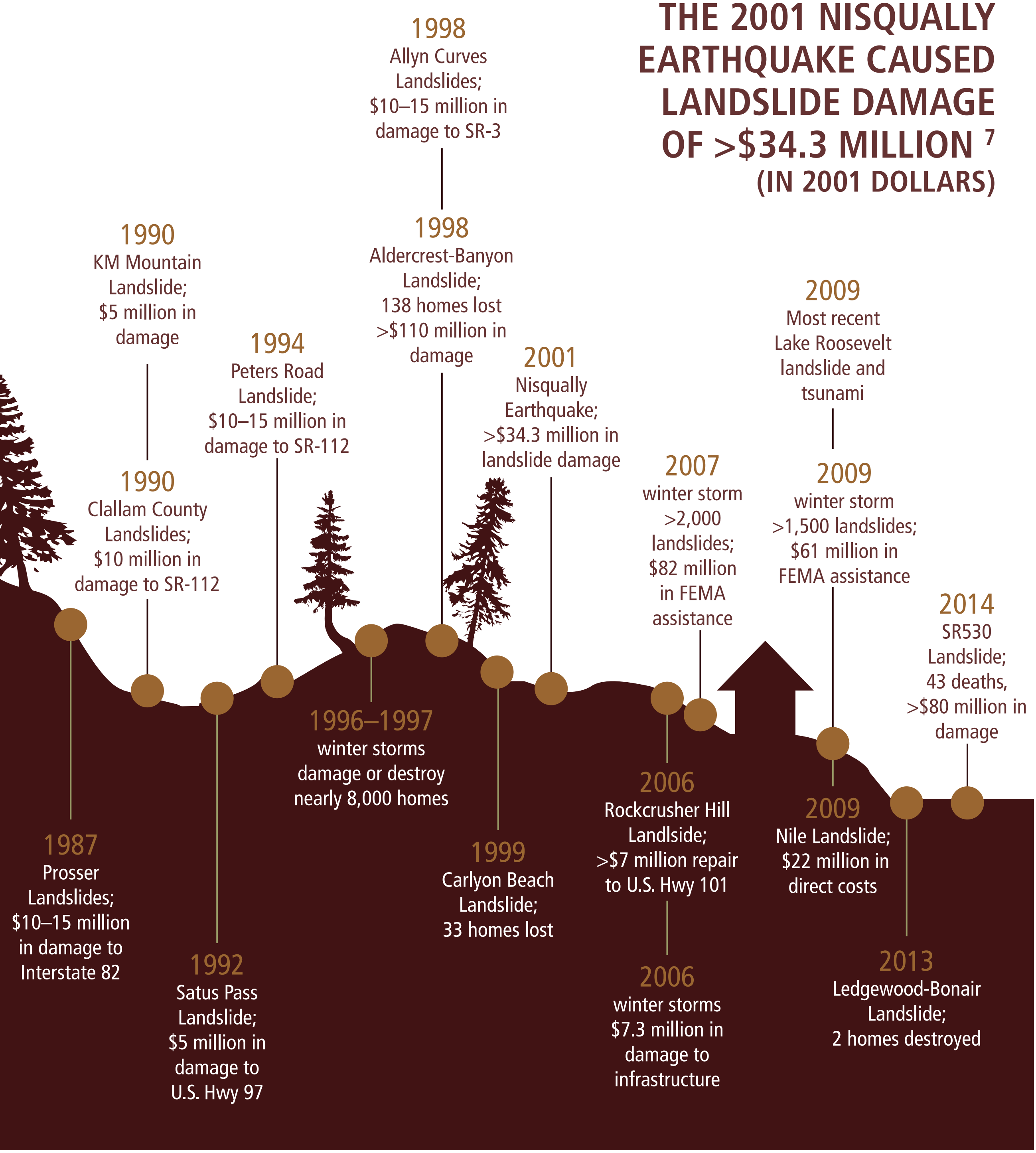
Landslides are one of the most frequently occurring natural hazards, but they're notoriously difficult to quantify both in terms of frequency and cost. Inventories of landslides for the state are not comprehensive, and in most cases, landslides are neither noticed nor reported.

Extreme winter precipitation events in western Washington can produce more than 1,500 landslides in a period of a few hours to weeks. And large, slow-moving slides destroy or damage homes and roads several times per month every winter.

Large and damaging events, such as the SR-530 (Oso) landslide or Aldercrest-Banyon in Kelso happen less frequently, but cost millions, and most of this damage is not covered by insurance. FEMA is relied upon in these large events to assist in loss recovery. Federal assistance frequently recovers only about 20 cents on the dollar. If no federal disaster declaration is made, assistance is more often zero.

THE 2001 NISQUALLY EARTHQUAKE CAUSED LANDSLIDE DAMAGE OF >$34.3 MILLION [7]

(IN 2001 DOLLARS)



THE PRINCIPAL HAZARDS POSED BY VOLCANOES ARE ASH FALL AND LAHARS

ASH FALL

Mount St. Helens (at least twelve eruptions in the last 4,000 years) and Glacier Peak (at least six eruptions in the last 4,000 years) are the Washington volcanoes most likely to produce ash.[9]

Ash eruptions pose a significant hazard to aircraft, and accumulations of ash can cause severe impact damage, respiratory problems, short-circuiting of electrical equipment, reduced visibility, fouling of machinery, and burial of structures, potentially causing roof collapse. Ash in a lateral blast can have devastating impacts near the volcano.

LAHARS

Lahars, or volcanic debris flows, can travel far from the volcano and inundate areas with mud tens of feet thick.

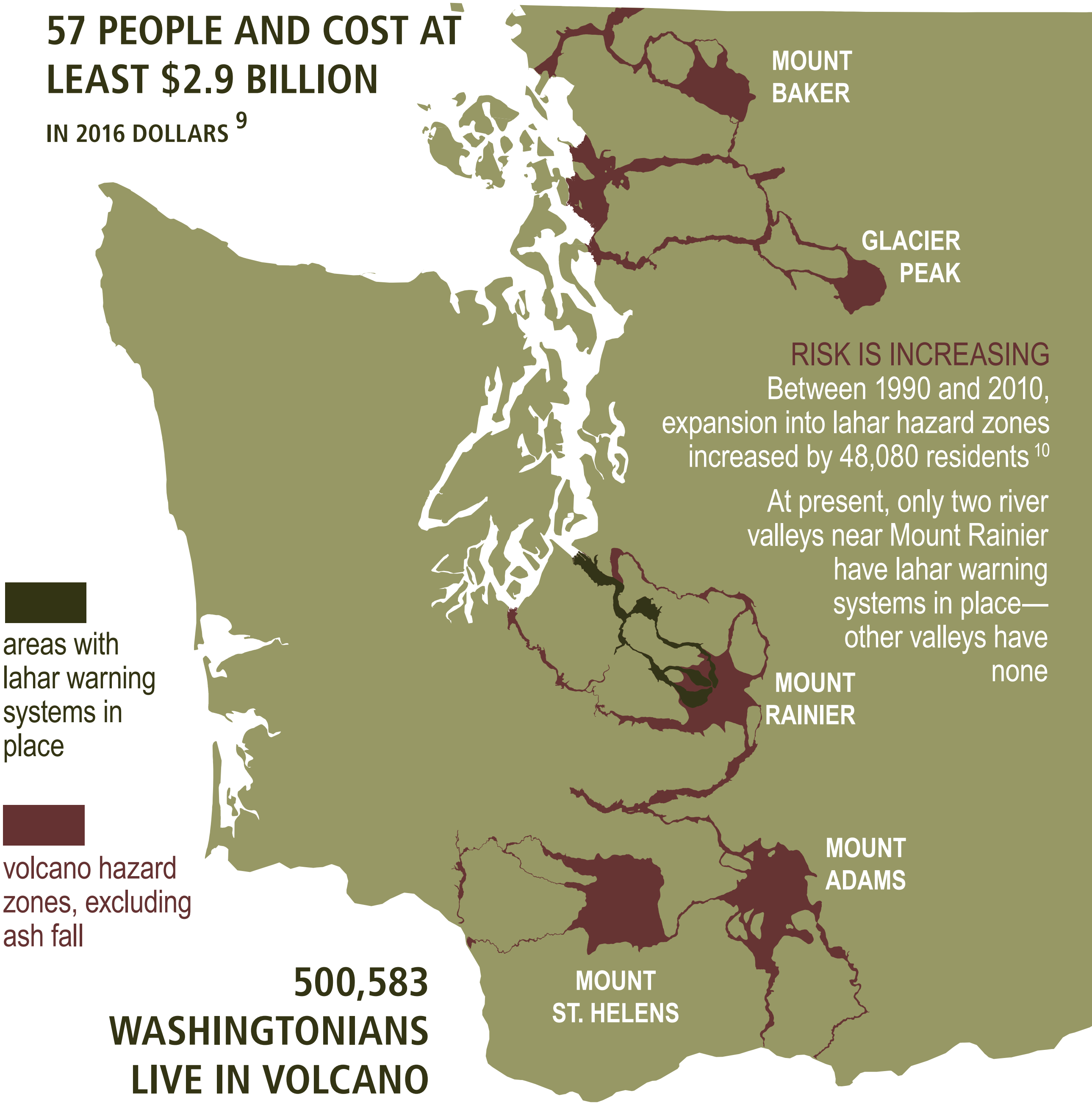
About 600 years ago, a large lahar buried the present site of the city of Orting 30 feet deep and likely continued to flow down the Puyallup River to Puget Sound. If this were to happen today, damage to structures would total an estimated **$13 billion.**[8]

Mount Rainier, Glacier Peak, and Mount Baker all pose this level of lahar hazard to significant population centers.

LAHARS THAT TRAVEL A SIGNIFICANT DISTANCE FROM THE VOLCANO HAVE RECURRENCE INTERVALS ON THE ORDER OF **500 YEARS**

THE 1980 ERUPTION OF MOUNT ST. HELENS KILLED 57 PEOPLE AND COST AT LEAST $2.9 BILLION

IN 2016 DOLLARS [9]

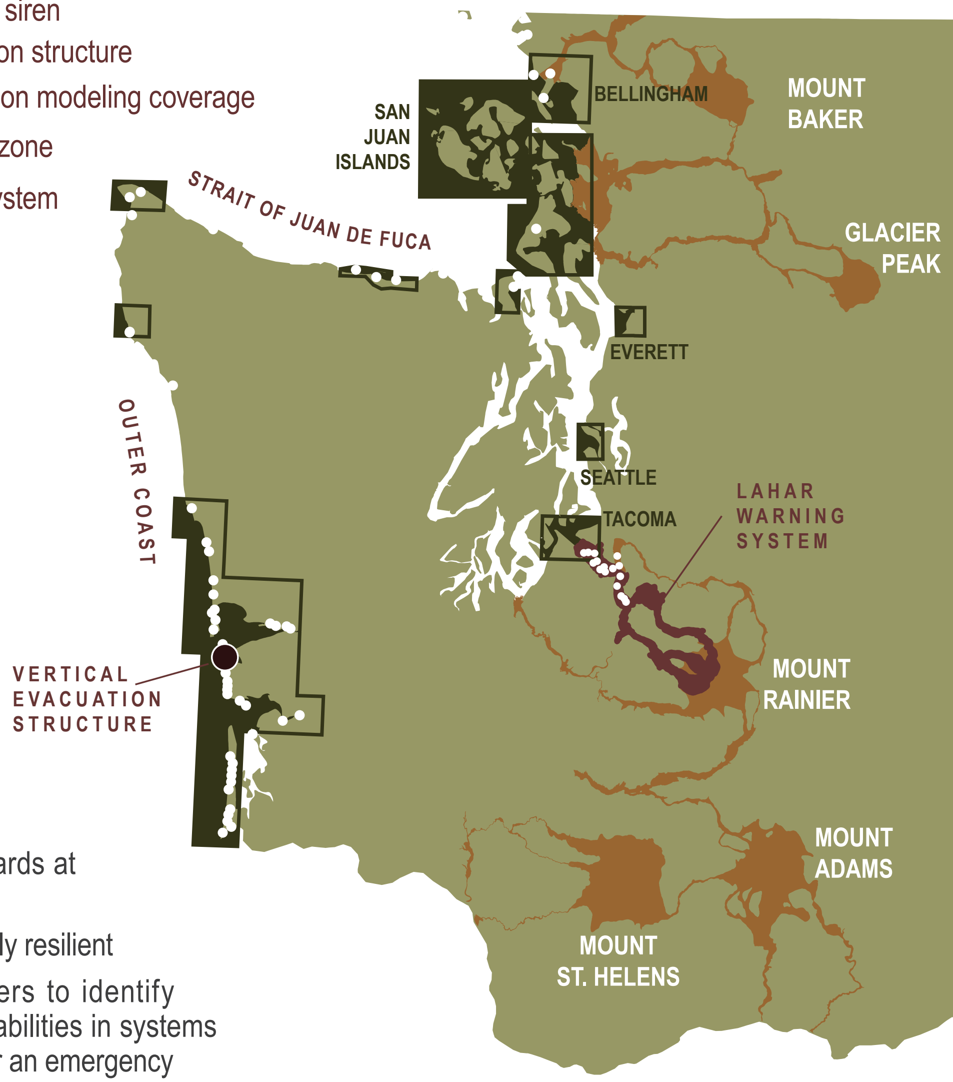


RISK IS INCREASING

Between 1990 and 2010, expansion into lahar hazard zones increased by 48,080 residents [10]

At present, only two river valleys near Mount Rainier have lahar warning systems in place—other valleys have none

500,583 WASHINGTONIANS LIVE IN VOLCANO HAZARD ZONES



WAYS TO REDUCE RISK AND LESSEN IMPACTS

- Evaluate geologic hazards at statewide level
- Make schools structurally resilient
- Require utility providers to identify and mitigate for vulnerabilities in systems before, during, and after an emergency
- Identify and replace aging or vulnerable infrastructure in areas of high seismic hazard
- Build additional vertical tsunami evacuation structures in vulnerable coastal communities to reduce loss of life
- Reinforce or replace unreinforced masonry buildings to better withstand shaking
- Enforce and update building codes
- Encourage and facilitate emergency planning at a community level
- Ensure continuity of health care after emergencies

RISK CAN BE REDUCED BY:

- mitigate the **hazard** through improvement of soil engineering properties
- limiting the **value** residing in hazard zones with improved hazard mapping, land-use planning, preparedness, and evacuation techniques
- limiting **vulnerability** to hazards, through improved building codes or relatively inexpensive seismic retrofits

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Washington Geological Survey

WE WORK TO REDUCE RISK AND FUTURE LOSSES FROM GEOLOGIC HAZARDS BY RAISING PUBLIC AWARENESS AND INFORMING TRAINED EXPERTS.

- HAZARD MAPPING
- ACTIVE FAULT STUDIES
- TSUNAMI INUNDATION MODELING
- LOCAL JURISDICTION ASSISTANCE
- SCIENCE ADVISORS
- EDUCATION AND OUTREACH
- EMERGENCY RESPONSE
- SOCIO-ECONOMIC LOSS MODELING

WITHOUT GEOLOGICAL HAZARD ASSESSMENTS, RISKS WOULD BE UNKNOWN, AND BUILDING STANDARDS WOULD BE BASED ON MERE GUESSWORK.

A RESILIENT SOCIETY PLANS FOR UNSCHEDULED EVENTS.

http://www.dnr.wa.gov/geology