Volcanic Eruption

A large volcano in the Pacific Northwest erupts, impacting the surrounding areas with lava flows and ash, and areas east with smoke and ash.

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high impacts. In addition, low and high impacts are not necessarily correlated with each other between different impact categories.

Category	Description	Metric	Low	Best	High
Health and Safety	Fatalities	Number of Fatalities	340[1]	515[2]	780[3]
	Injuries and Illnesses	Number of Injuries or Illnesses	2,000	17,000	150,000
Economic	Direct Economic Loss[4]	U.S. Dollars (2011)	$4.3 Billion[5]	$8.3 Billion[6]	$16.2 Billion[7]
Social	Social Displacement	People Displaced from Home ≥ 2 Days	1,300	130,000	2.1 Million
Psychological	Psychological Distress	Qualitative Bins	See text		
Environmental	Environmental Impact	Qualitative Bins[8]	High[9]		

LIKELIHOOD	Frequency of Events	Number of Events per Year	1/1000 yrs	1/500 yrs	1/100 yrs

Event Background

This volcanic hazard scenario focuses on community exposure to lahar (large, swift, and saturated debris flows produced by volcanoes) hazards and ashfall associated with Mount Rainier, Washington. Mount Rainier lahar flow affects four counties in the state of Washington: King County, Lewis County, Pierce County, and Thurston County. A majority of the hazard

[1] The 'Low' estimation was calculated by overlaying the Case I Debris Flow GIS boundary on 2000 U.S. Census designated census blocks to determine the affected population. 2010 U.S. Census data was not available during the time of analysis (July 2011).
[2] The 'Best' estimation is the geometric mean of 'Low' and 'High' possible fatalities.
[3] Community Exposure to Lahar Hazards from Mount Rainier, Washington; Nathan J. Wood and Christopher E. Soulard, USGS Scientific Investigations Report 2009-5211, September 16, 2009.
[4] The economic damage numbers reported here includes property damage and business interruption costs, but not lost demand due to fatalities and medical costs due to injuries. The SNRA project team determined that the property damage and business interruption costs dominated the direct economic damages of the scenario used for the volcanic eruption event to the extent that the multipliers for the other two components would have a negligible effect on the reported totals.
[5] The 'Low' estimation was calculated by overlaying the Case I Debris Flow GIS boundary was overlaid on 2000 U.S. Census designated census blocks to determine the affected population. 2010 U.S. Census data was not available during the time of analysis (July 2011).
[6] The 'Best' estimation is the geometric mean of 'low' and 'high' possible economic impacts.
[7] The 'High' estimate for economic impacts was calculated using previously collected data that was developed by overlaying and calculating the union of lahar-hazard zone, community boundaries, and block-level population counts compiled for the 2000 U.S. Census (2010 U.S. Census data was not available during the time of analysis). The economic loss amounts used are based on the total loss of annual sales generated by 3,890 businesses within lahar hazard areas.
[8] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental impacts for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[9] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.

areas are located in Pierce County. Mount Rainier is part of the Cascade Volcano range aligned in a north-south direction that roughly parallels the Pacific Ocean. Mount Rainier is the second highest peak in the conterminous U.S. at 14,410 feet (4,393 meters) and the largest single-peak glacial system in the U.S. Due to the proximity of over 1.5 million people living within the shadow of Mount Rainier, it is considered the most dangerous volcano in the Cascade Range.[10] The most populous city near Mount Rainier is Tacoma. Tacoma is approximately less than one mile from the lahar hazard area boundary.

The lahar hazard areas and debris flow paths used in this scenario are based on the behavior of the Electron Mudflow, a lahar that traveled along the Puyallup River approximately 500 years ago and was due to a slope failure on the west flank of Mount Rainier (Figure 1).[11]

The SNRA project team leveraged data from a 2009 study calculating community vulnerability to possible lahar hazards originating at Mount Rainier.[12]

Ash normally accompanies an eruption of a volcano and is composed of fine particles of fragmented volcanic rock (less than 2 mm diameter).[13] Ashfall is the accumulation of volcanic ash and a typical result of volcanic activity. Ashfall radius is dependent on wind direction, wind strength, and size of ash particles. The negative effects are dependent on the amount of ash accumulation. Ashfall with a thickness of 1/3 inch may cause disruption of ground and air transportation and cause damage to electronics and machinery, while four inches of ash could be sufficient to collapse building roofs. Ash can possibly produce acid rain when mixed with precipitation creating a form of diluted sulfuric acid.[14]

Volcanoes commonly repeat past behaviors, therefore historic ashfall and gas patterns were evaluated for Mount Rainier.[15] For this scenario, historic ashfall and gas patterns from Mount St. Helens were used. These patterns caused ash and gas to rise more than 15 miles vertically in 15 minutes. Clouds of ash can extend thousands of miles.[16] Mount St. Helens' heaviest ash deposition occurred in a 60 mile long swath immediately downwind of the volcano and thick ash deposits extended about 195 miles. During the 9 hours of vigorous eruptive activity, about 540 million tons of ash fell over an area of more than 22,000 square miles.[17] If similar ashfall were to occur as a result of Mount Rainier volcanic activity, the ash would reach westerly to Fort Lewis and easterly past the Snoqualmie National Forest.

Some possible negative consequences of ash include, but are not limited to:[18]

- Respiratory effects such as nasal irritation, throat irritation, and airway irritation
- Eye symptoms such as eye irritation, abrasions, discharge, or acute conjunctivitis
- Skin irritation

[10] Mount Rainier National Park: Geologic Resource Evaluation Report; U.S. Department of the Interior, National Park Service; Natural Resource Report NPS/NRPC/GRD/NRR—2005/007, September 2005.
[11] Community Exposure to Lahar Hazards from Mount Rainier, Washington; Nathan J. Wood and Christopher E. Soulard, USGS Scientific Investigations Report 2009-5211, September 16, 2009.
[12] All lahar hazard zone area boundaries used in calculations for this scenario are from the USGS 2009 study.
[13] Pierce County Hazard Identification and Risk Assessment: Volcanic; Pierce County Department of Emergency Management; 2010.
[14] The Health Hazards of Volcanic Ash: Guide for the Public. International Volcanic Health Hazard Network (IVHHN), 2003-2011; at http://www.ivhhn.org/index.php?option=com_content&view=article&id=55&Itemid=61 (accessed March 2013).
[15] Hazard Identification and Vulnerability Analysis (HIVA) of Walla Walla, Washington – Volcanic Ash Fall; Walla Walla County Emergency Management Department, October 2003.
[16] Volcanic Ash Fall – A "Hard Rain" of Abrasive Particles: USGS Fact Sheet 027-00; USGS, 2000.
[17] Eruptions of Mount St. Helens: Past, Present, and Future, U.S. Geological Survey Special Interest Publication: Ash Eruption and Fallout; Cascades Volcano Observatory (Robert I. Tilling, Lyn Topinka, and Donald A. Swanson); 1990.
[18] The Health Hazards of Volcanic Ash: Guide for the Public.

Figure 1 – Reference Map[19]

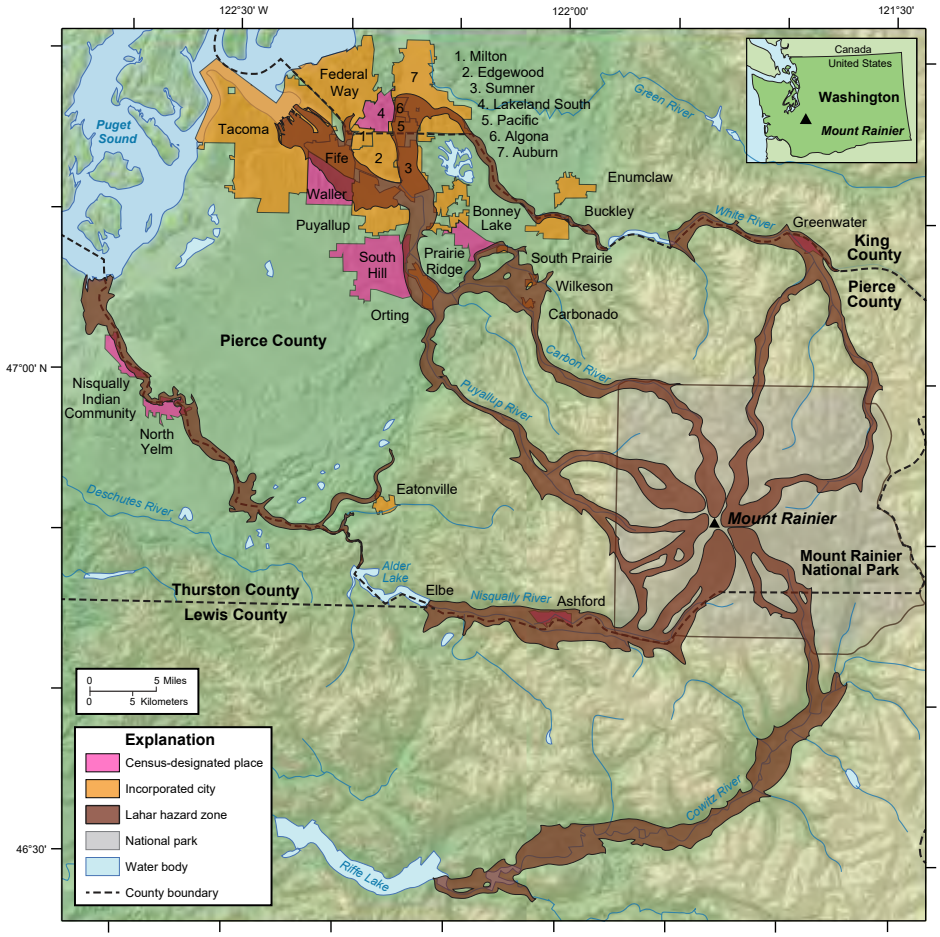


Figure 1. Map showing counties, incorporated cities, and census-designated places within a lahar-hazard zone on and near Mount Rainier, Washington (Hoblitt and others, 1998; Schilling and others, 2008).

- Indirect health effects such as reduction of visibility on roadways, increased demand on power leading to electricity loss, and effects on water supply creating possible contamination
- Disruption of ground and air transportation
- Major air routes pass downwind of the Cascade Volcanoes resulting in possible disturbance to flights and flight patterns
- Damage to electronics and machinery possibly affecting economic dynamics
- Crop damage causing agricultural loss
- Interruption of telephone, cell, and radio communications

[19] Wood and Soulard, *op. cit.*

Assumptions

Fatalities and Injuries

The SNRA project team used the following assumptions to estimate health and safety impacts resulting from a volcano event:

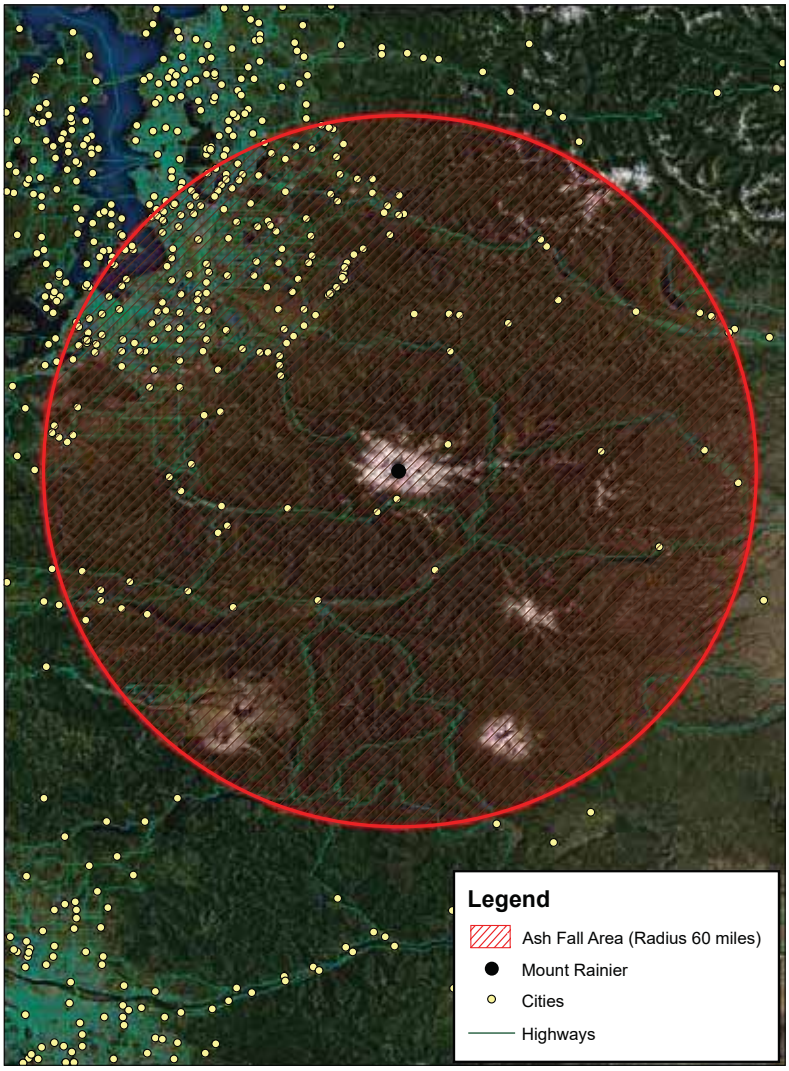
- The total population within lahar hazard areas was calculated using a GIS shapefile representing Inundation Zones for Case I Debris Flows.[20] Inundation Zones for Case I Debris Flows are areas that could be affected by cohesive debris flow that originates as enormous avalanches of weak chemically altered rock from the volcano. The Case I Debris Flow GIS boundary shapefile was used in this scenario because the layer covers a larger potentially hazardous area, and therefore includes all possibly vulnerable populations.
- One percent of the total population in lahar hazard areas was used as the amount of possible deaths in the health and safety impacts calculations because the total population is not at risk during Case I Debris Flow activity due to national, regional, state, and local monitoring systems, evaluation routes, and mitigation measures.[21] Further, one percent of the population was used to calculate possible deaths as a result of volcanic activity based on previous data from the 1980 Mount St. Helens eruption. 57 deaths occurred as a result of volcanic activity.[22] The Skamania County 1980 population was 8,289; therefore, 0.6% of the County's population was lost due to volcanic activity. This percentage was increased to 1% for this scenario in the event that a greater percentage of the population was at risk during eruption.
- The methodology used consists of overlaying and calculating the union of lahar-hazard zone, community boundaries, and block-level population counts compiled for the 2000 U.S. Census.[23]
- Possible tourist populations were not considered in any calculations.

To calculate injuries and illness amounts, a possible ashfall area with a radius of 60 miles from Mount Rainier (46.852947, -121.760424) was created and is depicted in Figure 2.[24]

- The radius buffer was overlaid on 2000 U.S. Census block data to determine the total population in the ashfall area. The ashfall area was distributed over an eight-county area: Cowlitz County, King County, Kittas County, Lewis County, Pierce County, Skamania County, Thurston County, and Yakima County. The population of the ashfall area was estimated to be approximately 1.5 million. For the 'High' estimate of injuries/illnesses, ten percent of the total population was determined to be vulnerable to injury or illness as a result of ashfall.[25]
- Wind direction and speed were not taken into account during this analysis.

[20] Digital Data for Volcano Hazards from Mount Rainier, Washington Revised 1998: Data to accompany U.S. Geological Survey Open-File Report 98-428; USGS; 2007.
[21] Danger Lurks Deep: The Human Impact of Volcanoes; Joanne Feldman and Robert I. Tilling, Division of Emergency Medicine at the Stanford University School of Medicine in Palo Alto, Calif., GeoTime November 2007.
[22] USGS Cascades Volcano Observatory, Vancouver, Washington Mount St. Helens, Washington. "On This Day in 1980" October 6, 1980 http://vulcan.wr.usgs.gov/Volcanoes/MSH/May18/OnThisDay1980/Days/1980October06.html.
[23] "Community Exposure to Lahar Hazards from Mount Rainier, Washington" by Wood and Soulard.
[24] A 60 mile radius was selected based on data from the actual Mt. St. Helens ashfall extents.
[25] Volcanic hazards: a sourcebook on the effects of eruptions: Academic Press; Blong, R.J., 1984, Australia, p. 424.

Figure 2 – Ashfall Radius



- Existing data did not include specific amounts for injuries and illness due to ashfall: therefore calculations for this scenario were performed using GIS technology.
- Ten percent of the population was used to calculate possible injury or illness as a result of volcanic activity based on previous data from the 1980 Mount St. Helens eruption. For this scenario it was estimated that 250 homes were damaged as a result of volcanic activity based on USGS calculations (USGS reports that more than 200 homes were destroyed).[26] The average household is comprised of an estimated 2.6 persons based on the U.S. Census. This resulted in an estimate that 650 people would be directly affected by the volcanic activity, or 7.3% of the county population. This percentage was increased to 10% for this scenario to include possible persons on transportation routes, working in the surrounding National Park, etc. Due to data limitations, only one radius layer was developed to calculate the "Best" estimation.

[26] USGS Cascades Volcano Observatory, Vancouver, Washington Mount St. Helens, Washington.

- For the 'Low' estimate of injuries/illnesses, the population in the State of Washington U.S. Census tracts immediately surrounding Mt. Rainier was used. Approximately 20,000 people live in the following Census tracts: Census Tract 30.01, Yakima County; Census Tract 701, Pierce County; Census Tract 9720, Lewis County; Census Tract 5238, Kittitas County; and Census Tract 315.02, King County. Ten percent of this population was determined to be vulnerable to injury or illness as a result of ashfall, as discussed above.[27]
- The 'Best' estimate of injuries/illnesses was calculated as the geometric mean of the 'Low' and High' estimates.

Economic Loss

The SNRA project team used the following assumptions to estimate the economic impacts resulting from a volcano event:

- The General Building Stock Dollar Exposure (Replacement Amount) designated by occupancy in census blocks was used to calculate the total dollar exposure of the combined amounts for commercial, industrial, agricultural, religion, government, and educational industries.
- Major transportation routes would be affected by possible volcanic activity. Interstate 5 and State Routes 161 and 167 are within Case I Debris Flow hazard areas, along with 195 major roadway segments. The obstruction of major roadways may have a negative impact on the economy due to supply and delivery delays, restrictions, and cancelations.
- A disruption in port activities resulting from volcanic activity could hinder job security and revenue, thus resulting in an economic loss for the state of Washington. More than 43,000 jobs in Pierce County and more than 113,000 jobs in Washington State are related to the Port activities. Port-related jobs generate $637 million in annual wages in Pierce County and more than $90 million annually in state and local taxes in Washington.[28] The Port of Tacoma is approximately 1 mile from the Case 1 Debris Flow hazard areas and vulnerable to possible volcanic activity.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- The number of homes destroyed in the output ranges of the HAZUS model gave low, best, and high estimates of numbers of persons displaced of 1,300, 130,000, and 2.1 million respectively.

Psychological Distress

Psychological impacts for the SNRA focus on significant distress and prolonged distress, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this

[27] U.S. Census data obtained from http://factfinder2.census.gov. Accessed on September 18, 2001.
[28] The Economic Impact of the Port of Tacoma; Port of Tacoma as prepared by Martin Associates; May 24, 2005.

index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[29] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental impacts for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental impact category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., as chemical or biological agents, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence (impact)[30] as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental impacts as "High." A volcanic eruption can cause disruption of aquatic life, eco-systems, etc. over a potentially large area. In addition, there are potential long-term climate change effects if airborne plume is extreme.

Potential Mitigating Factors

The consequences of a volcanic eruption will depend on the severity of the eruption, the sophistication of the monitoring and warning systems, and the level of preparedness (familiarity with evacuation routes, mitigation measures implemented, etc.) of the surrounding population areas that can be potentially affected by fallout from the eruption.

Additional Relevant Information

The average time interval between eruptions of Mount Rainier is estimated at 100 to 1,000 years.[31] For all impact calculations, the Inundation Zone for Case I Debris Flows used has a frequency of one event per 500 to 1,000 years.[32] These frequencies are based on the last 5,600

[29] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + \frac{1}{2}\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human impact metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological impacts. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Volcanic Eruption was given a C_{EF} of 1.0.

The specificity of the volcanic eruption event to a single geographic scenario precluded comparative judgments of risk on the psychological or other impact metrics with other events. This limitation will be addressed in a future national risk assessment.

[30] The 2011 SNRA referred to impacts as 'consequences' because of prior usage in quantitative risk assessment (Kaplan and Garrick [1981, March], On the quantitative definition of risk: *Risk Analysis* 1(1) 11-32). Except where it will cause confusion, 'impact' is used synonymously in this document because of pre-existing connotations of the word 'consequence' within FEMA.

[31] Volcano Hazards from Mount Rainier, Washington, Revised 1998: Open File 98-428; USGS; 1998.

[32] Ibid.

years. The annual probability of such a flow originating somewhere on Mount Rainier is thus about 0.1 to 0.2 percent. The debris flow reached the Puget Sound lowland about 600 years ago along the Puyallup River and is considered to be a characteristic Case I flow for purposes of identifying probable inundation areas.[33] The accounts of the most recent Mount Rainier volcanic event range from 1820 to 1870. According to the USGS, there is no immediate indication of renewed activity at Mount Rainier; however, due to the large population surrounding Mount Rainier hazard mitigation actions should be explored.

[33] Volcano Hazards from Mount Rainier, Washington, Revised 1998: Open File 98-428; USGS; 1998.